

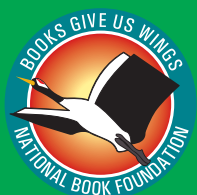
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Textbook of Chemistry

Grade

9



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Chemistry

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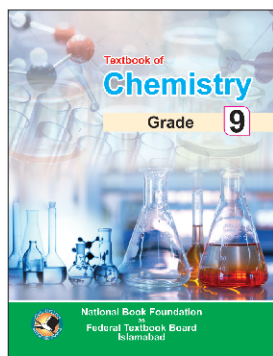
OUR MOTTO

• Standards • Outcomes • Access • Style

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Textbook of
Chemistry Grade - 9



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PREFACE

CHEMISTRY GRADE - 9 is developed according to the National Curriculum 2006 and National Style Guide. It is being published since 2012 and in 2015 it was presented under the new management and supervision of textbook development principles and guidelines with new design and layout.

Chemistry is one of the most exciting and useful subjects. It may not be an easy subject for you. If you develop a sound approach to thinking through an idea and solving problem, you will find it easy. This textbook provides several ways to develop this approach.

This textbook has been made friendly by giving problem solving strategy. This strategy is to facilitate reasoning, not memorizing toward a solution. With each skill or concept, self-assessment exercises have been given. These exercises would encourage students to think, develop skills and use information for a variety of purpose.

It is caused of development of skills such as questioning, observing, inferring, and predicting, measuring, hypothesizing, classifying, designing experiments, collecting data, analyzing data and interpreting data. At the end of each chapter summary of the key points is given. This provides quick reviews of the salient features of each chapter.

Science, Technology and Society connections have also been given in each chapter. These will help to understand the impact of science and technology on society. Students will learn how scientists decide what constitute scientific knowledge, how science is related to other ways of knowledge and how people have contributed to and influenced developments in science.

This textbook has been developed according to Student-Centered Inquiry Based (SCIB) criteria. It will encourage students to develop skills and think scientifically rather than simply memorize and study scientific facts. It is also expected from teachers that they will engage students in scientific inquiry activities to develop such skills.

Our efforts are to make textbooks teachable with quality, i.e. maintaining of standards. It is a continuous effort and we will get feedback of the yearly feasibility reports and redesign the textbook every year. The test items given in the exercises are for learning reinforcement. The examination questions should be prepared according to the SLO's and Bloom's Taxonomy.

Quality of Standards, Pedagogical Outcomes, Taxonomy Access and Actualization of Style is our motto. With these elaborations, this series of new development was presented for use. After educational feedback, research, NCC Standards 2016, the book is being published again.

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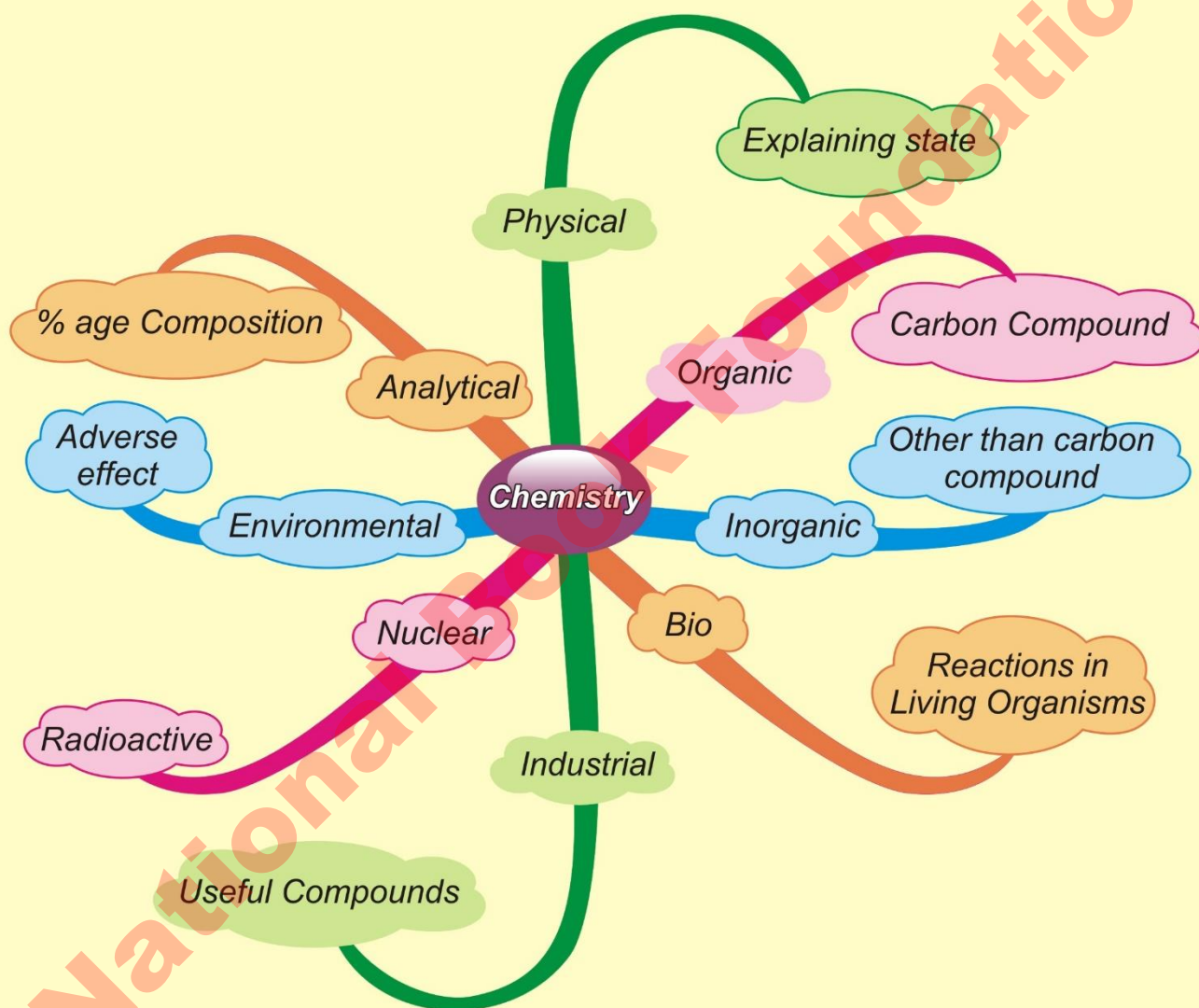
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اللہ کے نام سے شروع جو بڑا مہربان، نہایت رحم والا ہے

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MIND MAP





1

FUNDAMENTALS OF CHEMISTRY



This is a 15 days lesson

After completing this lesson, you will be able to:

- Change atomic mass, molecular mass and formula mass into gram atomic mass, gram molecular mass and gram formula mass.
- Differentiate between branches of chemistry.
- Differentiate between empirical and molecular formula.
- Differentiate among elements, compounds and mixtures.
- Differentiate between molecules and molecular ions
- Define ions, molecular ions, formula units and free radicals.
- Define atomic number, atomic mass, atomic mass unit.
- Define relative atomic mass based on C-12 scale.
- Distinguish between atoms and ions.
- Distinguish between ion and free radical. Classify the chemical species from given examples.
- Distinguish between matter and a substance.
- Describe how Avogadro's number is related to a mole of any substance. Distinguish among the terms gram atomic mass, gram molecular mass and gram formula mass.
- Identify the representative particles of elements and compounds.
- Identify and provide example of different branches of chemistry.
- Relate gram atomic mass, gram molecular mass and gram formula mass to mole.



Pre- Reading

What are the simplest components of wood, rocks and living organisms? This is an age-old question. Ancient Greek Philosophers believed that everything was made of an elemental substance. Some believed that substance to be water, other thought it was air. Some other believed that there were four elemental substances.

As 19th century began, John Dalton proposed an atomic theory. This theory led to rapid progress in chemistry. By the end of the century however, further observations exposed the need for a different atomic theory. 20th century led to a picture of an atom with a complex internal structure.

A major goal of this chapter is to acquaint you with the fundamental concepts about matter. In this chapter you will

learn some basic definitions to understand matter. This knowledge will help you in grade XI.

**Reading**

1.1 BRANCHES OF CHEMISTRY

Chemistry is defined as the science that examines the materials of the universe and changes that these materials undergo.

The study of chemistry is commonly divided into eight major branches:

1. Physical Chemistry

The branch of Chemistry that deals with laws and theories to understand the structure and changes of matter is called Physical Chemistry.

2. Organic Chemistry:

The branch of Chemistry that deals with substances containing carbon (Except carbonates, bicarbonates, oxides and carbides.

3. Inorganic Chemistry:

The branch of Chemistry that deals with elements and their compounds except organic compounds is called Inorganic Chemistry.

4. Biochemistry:

The branch of Chemistry that deals with physical and chemical changes that occur in living organisms is called Biochemistry.

5. Industrial Chemistry:

The branch of Chemistry that deals with the methods and use of technology in the large-scale production of useful substances is called industrial chemistry.

Do You Know?

Do you know the debate going on for centuries about the corpuscular nature of matter? An ancient Greek philosopher, Empedocles thought that all materials are made up of four things called elements:

1. Earth
2. Air
3. Water
4. Fire

Plato adopted Empedocles theory and coined the term element to describe these four substances. His successor, Aristotle also adopted the concept of four elements. He introduced the idea that elements can be differentiated on the basis of properties such as hot versus cold and wet versus dry. For example, heating clay in an oven could be thought of as driving of water and adding fire, transforming clay into a pot. Similarly water (cold & wet) falls from the sky as rain, when air (hot and wet) cools down. The Greek concept of four elements existed for more than two thousand years.

Society, Technology and Science

Archimedes was a Greek philosopher and mathematician and inventor of many war machines. Greek emperor gave him the task to determine whether his crown was made of pure gold or impure gold. Archimedes took the task and started thinking on it. He knew that the volume of an object determines the volume of the liquid it displaces, when submerged in the liquid. One day when he was taking bath, he observed that more water overflowed the bath tank as he sank deeper into the water. He also noticed that he felt weightless as he submerged deeper in the bath tank. From these observations he concluded that the loss in weight is equal to the weight of water overflowed. Thinking this he at once designed an experiment in his mind to check the purity of crown. He thought, he should weigh the crown and equal weight of the pure gold. Both should be dipped in water in separate containers, since every substance has different mass to volume ratio. If the crown was made of pure gold, it would displace same weight of water as an equal weight of pure gold. If the crown is impure, it would displace different mass of water than the pure gold. Thinking this, he was so excited that he ran from the bath shouting "Eureka" which means I have found it. Like Archimedes discovery, science developed through observations and experiments rather than by speculation alone.

**Teacher's Point**

Teacher may give examples of branches of Chemistry applied in daily life.



6. Nuclear Chemistry:

The branch of Chemistry that deals with the changes that occur in atomic nuclei is called nuclear chemistry.

7. Environmental Chemistry:

The branch of Chemistry that deals with the chemicals and toxic substances that pollute the environment and their adverse effects on human beings is called environmental chemistry.

8. Analytical Chemistry:

The branch of Chemistry that deals with the methods and instruments for determining the composition of matter is called Analytical Chemistry.

1.1.1 Differentiation between Branches of Chemistry

Vinegar contains 5% acetic acid. Acetic acid (CH_3COOH) is a colourless liquid that has characteristic vinegar like smell. It is used to flavour food. Various types of studies on this compound can help you to differentiate between various branches of chemistry.

1. Explanation of its transformation into gaseous state or solid state, applications of laws and theories to understand its structure is **physical chemistry**.
2. Since this is a carbon compound, its method of preparations and study of its physical and chemical characteristics is **organic chemistry**.
3. But the study of its component elements, carbon, hydrogen and oxygen is **inorganic chemistry**. This is because inorganic chemistry deals with elements and their compounds except carbon compounds. However, some carbon compounds such as CO_2 , CO, metal carbonates, hydrogen carbonates and carbides are studied in inorganic chemistry.
4. The study of chemical reactions that acetic acid undergoes in the bodies of human beings is **biochemistry**.

Society, Technology and Science

Theories are tentative. They may change if they do not adequately provide explanation of the observed facts. The work of scientists help to change existing theories of the time. In 1803, the British chemist John Dalton presented a scientific theory on the existence and nature of matter. This theory is called Dalton's atomic theory. Main postulates of his theory are as follows:

1. All elements are composed of tiny indivisible particles called atoms.
2. Atoms of a particular element are identical. They have same mass and same volume.
3. During chemical reaction atoms combine or separate or re-arrange. They combine in simple ratios.
4. Atoms can neither be created nor destroyed.

Dalton was able to explain quantitative results that scientists of his time had obtained in their experiments. He nicely explained the law of chemical combinations. His brilliant work became the main stimulus for the rapid progress of the chemistry during nineteenth century. However, series of experiment that were performed in 1850's and beginning of twentieth century clearly demonstrated that atom is divisible and consists of subatomic particles, electrons, protons and neutrons. Also the atoms of an element may differ in masses (such atoms are called isotopes). Thus some of the postulates of Dalton's atomic theory were found defective and were changed.



5. Use of technology and ways to obtain acetic acid on the large scale is **industrial chemistry**.
6. The study of the effect of radioactive radiations or neutron on this compound or its component elements is **nuclear chemistry**.
7. The study of any adverse effects of this compound or the compounds that are derived from it, on the humans is **environmental chemistry**.
8. The method and instruments used to determine its percentage composition, melting point, boiling point etc is **analytical chemistry**.

Example 1.1: Identifying examples of different branches of chemistry

Identify the branch of chemistry in each of the following examples:

1. Photosynthesis produces glucose and oxygen from carbon dioxide and water in presence of chlorophyll and sunlight.
2. Plantation helps in overcoming green house effect.
3. Haber's process converts large quantities of hydrogen and nitrogen into ammonia (NH_3).
4. Ammonia is a colourless gas with pungent irritating odour. It is highly soluble in water.
5. A chemist performed an experiment to check the percentage purity of a sample of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$).
6. An analyst determines that NO_2 is responsible for acid rain.
7. Chlorofluorocarbon compounds are responsible for the depletion of ozone layer.
8. α -particles (He^{++}) when bombard on nitrogen atom, a proton is emitted.

Problem Solving strategy:

Concentrate on the basic definition of each branch of chemistry and identify branch of chemistry in each example.

Solution:

1. Biochemistry, since photosynthesis is a chemical reaction that occurs in plants (living organism).
2. Environmental chemistry, since green house effect is an environmental problem.
3. Industrial chemistry, since large scale production of any substance is the subject of industrial chemistry.
4. Inorganic chemistry, since it deals with properties of inorganic compounds.
5. Analytical chemistry, since it deals with analysis of a compound, whether organic or inorganic in nature.
6. Environmental chemistry, since acid rain is an environmental problem.
7. Environmental chemistry, since depletion of ozone layer is environmental problem.
8. Nuclear chemistry, since nuclear change can emit protons.



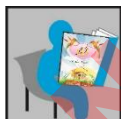
Self-Assessment Exercise 1.1

Identify the branch of chemistry that is related to the following information:

1. Hair contain a special class of proteins called keratins, which are present in nails and wool. Proteins contain chains of C-atoms.
2. Acetylene is the simplest hydrocarbon that contains carbon-carbon triple bond. Hydrocarbons are the compounds of carbon and hydrogen.
3. White lead is a pigment used by artists for centuries, the metal Pb in the compound is extracted from its ore, galena (PbS).
4. Sulphuric acid (H_2SO_4) is extremely corrosive to skin.
5. Gases can be compressed by applying pressure.
6. Meat, Milk and eggs contain long chains of carbon compounds.
7. Element radium decays by emitting α -particles and is converted into another element radon.
8. Calorimeter is a device that measures the amount of heat, a substance absorbs on heating or emits on cooling.

Society, Technology and Science Molecularity of the physical world

World is composed of a few more than a hundred elements. Elements are building blocks of all the substances that make up all living and non-living things. This means elements are building blocks for everything in the universe. The same elements that make up earth also make up moon. A careful observation of the physical world reveals that matter usually occurs as mixtures. Most of the components of these mixtures are elements and compounds that exist as molecules. Only noble gases exist as monoatomic molecules, other substances exist as polyatomic molecules. Air consists of many elements and compounds all existing in molecular form. For instance O_2 , N_2 , CO_2 , H_2O and the noble gases. Water a molecular substance cover 70% of the earth's crust. It also fills the empty under the earth. Rocks and earth are mixtures of numerous compounds. Clay and sand consists of long chains of atoms called giant molecules. Petroleum and coal that are complex mixtures also contain hundreds of thousands of molecular compounds. Living things contain thousands of different substances such as carbohydrates, proteins, fats, lipids, DNA, RNA etc. All these substances are molecular in nature.



Reading

1.2 BASIC DEFINITIONS

Some of the important definitions used to understand matter are given below:

1.2.1 Elements, Compounds and Mixtures

Anything that occupies space and has mass is called matter. Any matter that has a particular set of characteristics that differ from the characteristics of another kind of matter is called a substance. For instance, oxygen, water, carbon dioxide, urea, glucose, common salt etc are different substances.



A substance that cannot be converted to other simpler substances is called an element. For example substances like oxygen, hydrogen, iron, copper, aluminium etc are elements. An element is now defined as a substance whose all the atoms have the same atomic number.

A compound is a pure substance that consists of two or more elements held together in fixed proportions by natural forces called chemical bonds. The properties of compounds are different from the properties of the elements from which they are formed. For example, water, carbon dioxide, copper sulphate, sodium chloride etc are compounds. Elements and compounds have uniform composition throughout.

An impure substance that contains two or more pure substances that retain their individual chemical characteristics is called a mixture. A mixture can be converted into two or more pure substances by a physical method. Examples of mixture are air, water containing dissolved oxygen, table salt dissolved in water, salt + sand etc. A mixture that consists of two or more visibly different components is called a heterogeneous mixture. For example sand + salt, oil floating on water etc. A mixture that consists of only one phase is called a homogeneous mixture. For example, sugar mixed in water, salt dissolved in water. Homogeneous mixtures also have uniform composition throughout.

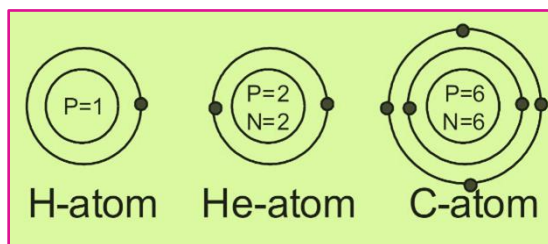
Science Tit Bits

Bad breath may be good for you. The chemistry of garlic is not simple. Garlic contains more than 200 compounds. People who eat a lot of garlic have a lower chance of getting stomach cancer, suffering from heart disease or having a stroke than people who eat little or no garlic.

In fact the entire physical world is made up of mixture of elements and compounds. Most of its components are made up of molecules.

1.2.2 Atomic Number, Mass Number

The number of protons in the nucleus of an atom is known as its atomic number. For example, there is only one proton in the nucleus of H-atom; therefore its atomic number is 1. All the atoms of a given element have the same number of protons and therefore the same atomic number. Do you think atomic number of He is 2? What is the mass number of C-atom? **The total number of protons and neutrons in an atom is known as its mass number.**



Some atoms of an element have different number of neutrons, such atoms are called isotopes. We will discuss isotopes in section 2.2.

$$\text{No. of neutrons} = \text{mass number} - \text{atomic number}$$

Example 1.2: Determining the number of protons and neutrons in an atom

Atomic number of an element is 17 and mass number is 35. How many protons and neutrons are in the nucleus of an atom of this element?

Problem Solving Strategy:

Number of protons are equal to atomic number and

Number of neutrons = mass number – atomic number



Solution:

Number of protons = atomic number = 17

Number of neutrons = mass number – atomic number
 $= 35 - 17 = 18$

1.2.3 Relative Atomic Mass and Atomic Mass Unit

The first quantitative information about atomic masses came from the work of Dalton, Gay Lussac, Lavoisier, Avogadro and Berzelius. By observing the proportions in which elements combine to form various compounds, nineteenth century chemists calculated relative atomic masses. An atom is extremely small particle; therefore we cannot determine the mass of a single atom. However, it is possible to determine the mass of one atom of an element relative to another experimentally. This can be done by assigning a value to the mass of one atom of a given element, so that it can be used as standard. By international agreement in 1961, light isotope of carbon C-12 has been chosen as a standard. This isotope of carbon (C-12) has been assigned a mass of exactly 12 atomic mass unit. This value has been determined accurately using mass spectrometer. The mass of atoms of all other elements are compared to the mass C-12. Thus **“the mass of an atom of an element relative to the mass of an atom of C-12 is called its relative atomic mass”**.

One atomic mass unit (amu) is defined as a mass exactly equal to one-twelfth the mass of one C-12 atom.

Mass of one C-12 atom = 12 amu

$$1 \text{ amu} = \frac{\text{mass of one C-12 atom}}{12}$$

A hydrogen atom is 8.40% as massive as the standard C-12 atom. Therefore, relative atomic mass of hydrogen.

$$\begin{aligned} &= \frac{8.40}{100} \times 12 \text{ amu} \\ &= 1.008 \text{ amu} \end{aligned}$$

Similarly, relative atomic masses of O, Na, Al are 15.9994 amu, 22.9898 amu, 26.9815 amu respectively. Table 1.1 shows the relative atomic masses of some elements.

Table 1.1 relative atomic masses of some elements

Element	Relative atomic mass	Element	Relative atomic mass
H	1.008 amu	Al	26.9815 amu
N	14.0067 amu	S	32.06 amu
O	15.9994 amu	Cl	35.453 amu
Na	22.9898 amu	Fe	55.847 amu



1.2.4 Empirical Formula, Molecular Formula

Recall that the chemical formula of a compound tells us which elements are present in it and the whole number ratio of their atoms. In a chemical formula element's symbol and numerical subscripts show the type and the number of each atom in a compound. There are several types of chemical formulas for a compound. Here you will learn about two types of chemical formulas.

1. Empirical Formula

The empirical formula of a compound is the chemical formula that gives the simplest whole-number ratio of atoms of each element. For example in compound hydrogen peroxide there is one H atom for every O atom. Therefore, simplest ratio of hydrogen to oxygen is 1 : 1. So the empirical formula of hydrogen peroxide is written as **HO**.

The simplest ratio between C, H and O atoms in glucose is 1 : 2 : 1. What is the empirical formula of glucose?

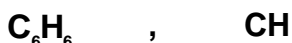
2. Molecular Formula

A molecular formula gives the actual whole number ratio of atoms of each element present in a compound. For example there are actually two H atoms and two O atoms in each molecule of hydrogen peroxide. Therefore, actual ratio of hydrogen to oxygen atoms is 2 : 2. So molecular formula of hydrogen peroxide is **H₂O₂**.

The actual ratio between C, H and O atoms in a glucose molecule is 6 : 12 : 6. What is the molecular formula of glucose?

An empirical formula shows the simplest number of atoms of each element in a compound whereas the molecular formula shows the actual number of atoms of each element in the molecule of a compound.

Benzene is a compound of carbon and hydrogen. It contains one C atom for every H atom. There are actually six C atoms and six hydrogen atoms in each molecule of benzene. Identify empirical and molecular formula for benzene from the following formulas.



Molecular formulas for water and carbon dioxide are H₂O and CO₂ respectively. What are empirical formulas for these compounds?



Self-Assessment Exercise 1.2

Write the empirical formulas for the compound containing carbon to hydrogen in the following ratios:

- (a) 1:4 (b) 2:6 (c) 2:2 (d) 6:6

For many compounds, empirical and molecular formulas are same. For example water (H₂O), carbon dioxide (CO₂), ammonia (NH₃), methane (CH₄), sulphur dioxide (SO₂) etc. Can you show it why?



Teacher's Point

A teacher may give numerical example to determine E.F of a Compound.



Self-Assessment Exercise 1.3

1. Aspirin is used as a mild pain killer. There are nine carbon atoms, eight hydrogen atoms and four oxygen atoms, in this compound. Write its empirical and molecular formulas.
2. Vinegar is 5% acetic acid. It contains 2 carbon atoms, four hydrogen atoms and 2 oxygen atoms. Write its empirical and molecular formulas.
3. Caffeine ($\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$) is found in tea and coffee. Write the empirical formula for caffeine.



Reading

1.2.5 Molecular Mass and Formula Mass

Molecular mass is the sum of atomic masses of all the atoms present in the molecule. All you have to do is to add up the atomic masses of all the atoms in the compound. For example,

$$\begin{aligned}
 \text{Molecular mass of water } \text{H}_2\text{O} &= 2(\text{atomic mass of H}) + \text{atomic mass of oxygen} \\
 &= 2(1.008) + 16.00 \\
 &= 2.016 + 16.00 \\
 &= 18.016 \text{ amu}
 \end{aligned}$$

Example 1.3: Determining molecular mass

1. Determine the molecular mass of glucose $\text{C}_6\text{H}_{12}\text{O}_6$ which is also known as blood sugar.
2. Determine the molecular mass of naphthalene C_{10}H_8 , which is used in mothballs.

Problem solving strategy:

Multiply atomic masses of carbon, hydrogen and oxygen by their subscripts and add.

Solution:

1. Molecular mass of $\text{C}_6\text{H}_{12}\text{O}_6$

$$\begin{aligned}
 &= 6(12.00) + 12(1.008) + 6(16.00) \\
 &= 180.096 \text{ amu}
 \end{aligned}$$
2. Molecular mass of C_{10}H_8

$$\begin{aligned}
 &= 12 \times 10 + 1 \times 8 \\
 &= 120 + 8 = 128 \text{ amu}
 \end{aligned}$$

The term molecular mass is used for molecular compounds. Whereas, the term formula mass is used for ionic compounds. Ionic compounds consist of arrays of oppositely charged ions rather than separate molecules. So we represent an ionic compound by its formula unit. A formula unit indicates the simplest ratio between cations and anions in an ionic compound. For example, the common salt consists of Na^+ and Cl^- ions. It has one Na^+ ion for every Cl^- ion. So formula unit for common salt is NaCl .

The sum of the atomic masses of all the atoms in the formula unit of a substance is called formula mass.

**Example 1.4: Determining formula mass**

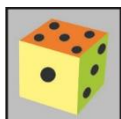
1. Sodium Chloride, also called as table salt is used to flavour food, preserve meat, and in the preparation of large number of compounds. Determine its formula mass.
2. Milk of magnesia which contains $\text{Mg}(\text{OH})_2$, is used to treat acidity. Determine its formula mass.

Problem solving strategy:

Add the atomic masses of all the atoms in the formula unit.

Solution:

1. Formula mass of NaCl $= 1 \times \text{Atomic mass of Na} + 1 \times \text{Atomic mass of Cl}$
 $= 1 \times 23 + 1 \times 35.5$
 $= 58.5 \text{amu}$
2. Formula mass of $\text{Mg}(\text{OH})_2 = 24 + 16 \times 2 + 1 \times 2$
 $= 24 + 32 + 2$
 $= 58 \text{amu}$

**Self-Assessment Exercise 1.4**

1. Potassium Chlorate (KClO_3) is used commonly for the laboratory preparation of oxygen gas. Calculate its formula mass.
2. When baking soda, NaHCO_3 is heated carbon dioxide is released, which is responsible for the rising of cookies and bread. Determine the formula masses of baking soda and carbon dioxide.
3. Following compounds are used as fertilizers. Determine their formula masses.
 - (i) Urea, $(\text{NH}_2)_2\text{CO}$
 - (ii) Ammonium nitrate, NH_4NO_3 .

**Reading****Important information**

Many scientists regarded atom as merely a convenient mental construct and nothing more. This is because atom is so small that it cannot be seen with the naked eye. Today, however, we have sophisticated instruments to weigh atoms and even visualize them. Figure 1.1 shows an image of gold atoms on the surface.

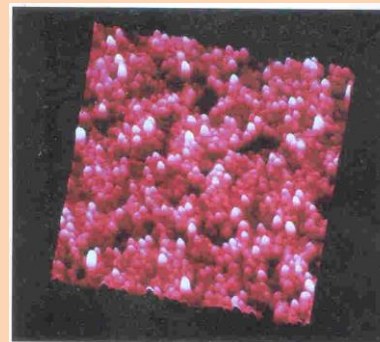


Figure 1.1 view of surface atoms of gold

The image has been drawn by computer from signal sent to it by an instrument called a scanning tunneling microscope. The computer has drawn gold atoms as topped peaks.

1.3 CHEMICAL SPECIES

Most of the matter is composed of molecules or ions, formed by atoms.



1.3.1 Ions (Cation, Anions), Molecular Ions and Free Radicals

Atom is the smallest particle of an element that cannot exist in free state. It is electrically neutral. On the other hand an ion is a charged species formed from an atom or chemically bonded groups of atoms by adding or removing electrons. **Positively charged ions are called cations, whereas, the negatively charged ions are called anions.** An ionic compound

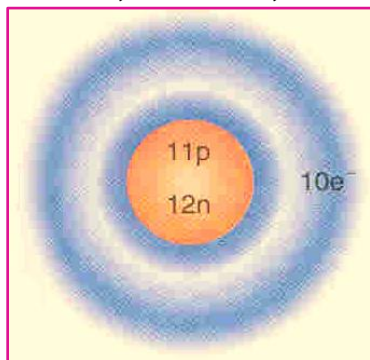
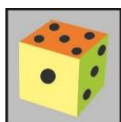


Fig.1.2 Na⁺ ion

contains anions and cations in such number that the compound is electrically neutral. Metal atoms generally lose one or more electrons and form cations. For example Na forms Na⁺ by losing one electron, Ca forms Ca⁺² by losing two electrons. The Non-metal atoms usually gain one or more electrons and form anions. For example a chlorine atom gains one electron and forms Cl⁻ ion. An O-atom gains two electrons and forms O⁻² ion.

Let us understand why an ion acquires a net positive or negative charge. Consider the formation of Na⁺ ion.

Figure 1.2 shows the sodium ion. Note that sodium has a nucleus of 11 protons and 12 neutrons. Thus its nucleus has a total charge of +11. Around the nucleus, there are 10 electrons, with a total charge of -10. The charge on the ion is $+11 + (-10) = +1$



Self-Assessment Exercise 1.5

Explain Why?

1. An oxide ion O⁻² has -2 charge.
2. Magnesium ion, Mg⁺² has +2 charge.
3. Sulphide ion, S⁻² has -2 charge.



Reading

Molecular Ion

When a molecule loses or gains one or more electrons, the resulting species is called a **molecular ion**. For example O₂ when loses one electron it forms O₂⁺ ion, but when it absorbs an electrons it forms O₂⁻ ion. These ions are called molecular ions. Similarly N₂⁻, N₂⁺ etc are examples of molecular ions. These are short lived species and only exist at high temperature. Molecular ions do not form ionic compounds.

Free Radicals

A free radical is an atom which has an unpaired electron and bears no electrical charge. For example



are free radicals



When substances like halogens are exposed to sun light, their molecules split up into free radicals.

Difference between Ion and Free Radical



Chlorine free radical



Chloride ion

Which species has even number of electrons? Which species has odd number of electrons?

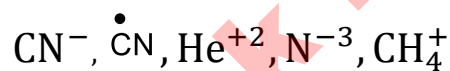
A free radical has an unpaired electron, so it has odd number of electrons. A free radical is an electrically neutral species. Whereas an ion has even number of electrons, so it has no unpaired electrons.

Dot (.) indicates an unpaired electron.



Self-Assessment Exercise 1.6

Identify ions, molecular ions and free radicals from the following species.



Reading

1.3.2 Representative Particles of Elements and Compounds

The term representative particles refer to species present in a substance. These species are atoms, molecules or formula units. For instance water exists as molecules, carbon exists as atoms.

Example 1.5: Identifying representative particles of elements and compounds

Figure 1.3 shows some molecules. Identify particles of elements and compounds.

Problem Solving Strategy:

Elements have atoms of same sizes and compounds have atoms of different sizes.

Solution:

Particles of elements are A, C, D and E. Particles of compounds are B and F.

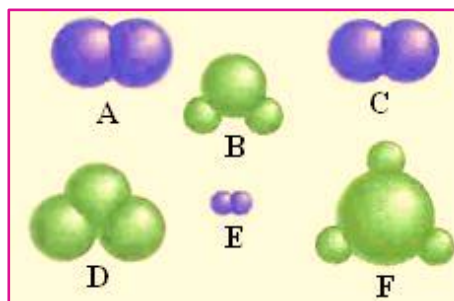
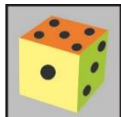


Fig 1.3 Some common molecules

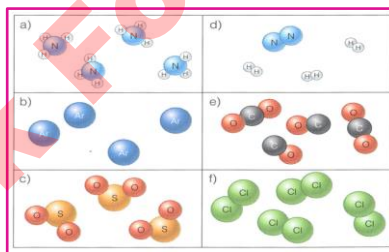
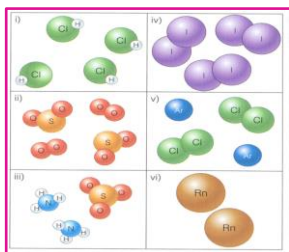


Molecules can also be classified as monoatomic or polyatomic. Inert gases consist of monoatomic molecules such as He, Ne, Ar, Kr, Rn. **A molecule that contains only one atom is called monoatomic. Molecules that contain two or more similar or different atoms are called polyatomic molecules.** For example, H_2 , O_2 , HCl, NH_3 etc are polyatomic molecules.



Self-Assessment Exercise 1.7

- Observe the given figure and identify the diagrams that represents the particles of :
 - An element whose particles are atoms.
 - An element whose particles are molecules.
 - A compound.
 - A mixture of an element and a compound.
 - A mixture of two elements.
 - A mixture of two compounds.
- Observe the given figure and decide which diagram represents particles in an element, a compound or a mixture.



Reading

1.4 AVOGADRO'S NUMBER AND MOLE

How do you count shoes? As shoes come in pairs, so you would most likely count them by pairs rather than individually. Similarly eggs, oranges etc. are counted in dozens, but paper by ream. Thus, the counting unit depends on what you are counting.

Chemists also use a practical unit for counting atoms, molecules and ions. They use a counting unit called mole to measure the amount of a substance.

A mole is an amount of a substance that contains 6.022×10^{23} particles of that substance. This experimentally determined number is known as Avogadro's number. It is represented by N_A . Just as a dozen eggs represent twelve eggs, a ream of paper represent 500 papers, a mole of a substance represents 6.022×10^{23} representative particles of a substance..

Society, Technology and Science

During 600 – 1600 AD, Chemical history was dominated by a pseudo-science called alchemy. Earlier alchemists were obsessed with the idea of turning cheap metals into gold. They searched for ways to change less valued metals such as lead into gold. They could not succeed and wasted their time and money. Therefore, the works of earlier alchemists handicapped progress of science. However, during that period they discovered many new processes such as distillation, sublimation and extraction. These processes are still in use today. Such processes are contributing a lot in the progress of science. This means the works of different scientists at the same time handicap or promote the growth of science.



For example a mole of carbon is 6.022×10^{23} atoms. A mole of sulphur is 6.022×10^{23} atoms. A mole of water is 6.022×10^{23} molecules.

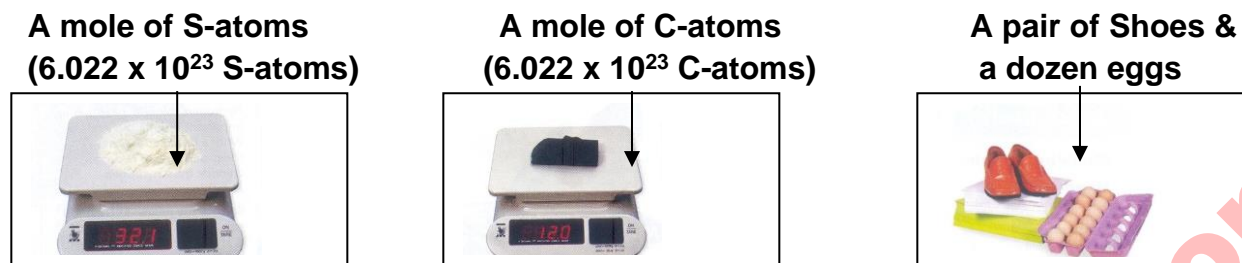


Figure 1.4 A mole of S-atoms, a mole of C-atoms & pair of Shoes & a dozen eggs

What is the mass of one mole C-atoms?

How many atoms are there in 32.1 g of S-atoms?

Does a dozen eggs have same mass as a dozen bananas? Does a mole of carbon atoms have a different mass than a mole of sulphur atoms?

The mass of one mole of substance is called as molar mass. What are the molar masses of carbon and sulphur? The term representative particles in a substance are atoms, molecules, formula units or ions. For instance water exists as molecules, therefore, one mole of water contains 6.022×10^{23} molecules of water. Hydrogen exists as H_2 molecules, so one mole of hydrogen contain 6.022×10^{23} molecules. Carbon exists as atoms so 1 mole of carbon contains 6.022×10^{23} atoms.

Society, Technology and Science Size of the Mole

Entire population cannot count 1 mole of coins in a year. They need about one million year to count them. So, when counting a pile of coins, it would not be convenient to count them one by one. The concept of mole has given a very simple method to count large number of items. Mole is not only a number but also represents definite amount of a substance. Just as 6.02×10^{23} carbon atoms weigh 12 g, 6.02×10^{23} coins will also have a definite mass. So an easy way is to weigh them. If you know the mass of one coin, you can count them by weighing.

1.4.3 Gram Atomic Mass, Gram Molecular Mass and Gram Formula Mass

A mole of S-atoms
(6.022×10^{23} S-atoms)



What is the mass of 6.022×10^{23} S-atoms?
Is this mass of S-atoms equal to its atomic mass?

A mole of C-atoms
(6.022×10^{23} C-atoms)



What is the mass of one mole of C-atoms?
Is this mass of C-atoms equal to its atomic mass?



Teacher's Point

Teacher may give more examples of mole.



Atomic mass of an element expressed in grams is called gram atomic mass.

Is the gram atomic mass of C-atoms 12 g?

What is the gram atomic mass of S-atoms?

If each of the carbon and sulphur sample shown above contains one mole of atoms, why do the samples have different masses?

Atomic mass of C = 12amu \therefore gram atomic mass of C = 12g

Atomic mass of Na = 23amu \therefore gram atomic mass of C = 23g

Atomic mass of Zn = 63.54amu \therefore gram atomic mass of C = 63.54g

Gram atomic mass of an element contains 1 mole of atoms.

Therefore,

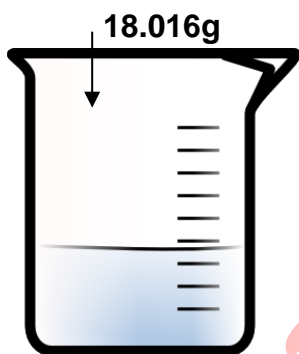
Mass of 1 mole of C-atoms = 12g

Mass of 1 mole of Na-atoms = 23g

Mass of 1 mole of Zn-atoms = 63.54g

A mole of H_2O -molecules

$(6.022 \times 10^{23} \text{ H}_2\text{O-molecules})$

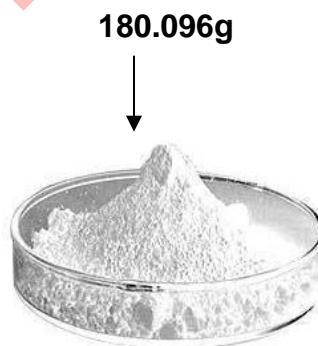


What is the mass of one mole of water molecules?

Is this mass of water molecules equal to molecular mass of water?

A mole of $\text{C}_6\text{H}_{12}\text{O}_6$ – molecules

$(6.022 \times 10^{23} \text{ C}_6\text{H}_{12}\text{O}_6 \text{-molecules})$



what is the mass of 6.022×10^{23} molecules of glucose?

is this mass of glucose molecules equal to molecular mass of glucose?

Molecular mass of a substance expressed in grams is called gram molecular mass.

Molecular mass of H_2O = $2 \times 1.008 + 16$

= 18.016amu

So, gram molecular mass of H_2O = 18.016g

Molecular mass of $\text{C}_6\text{H}_{12}\text{O}_6$ = $6 \times 12 + 12 \times 1.008 + 16 \times 6$

= 180.096amu

So, gram molecular mass of $\text{C}_6\text{H}_{12}\text{O}_6$ = 180.096g



Formula mass of a substance expressed in gram is called gram formula mass.

An ionic compound is represented by the formula unit that represents the simplest ratio between the ions of a compound. For example NaCl, KCl, CuSO_4 etc.

$$\begin{aligned}\text{Formula mass of NaCl} &= 23 + 35.5 \\ &= 58.5\text{amu}\end{aligned}$$

Therefore, gram formula mass of NaCl = 58.5g = mole of NaCl formula units.

$$\begin{aligned}\text{Formula mass of KCl} &= 39 + 35.5 \\ &= 74.5\text{amu}\end{aligned}$$

So, gram formula mass of KCl = 74.5g

Difference between the Terms Gram Atomic Mass, Gram Molecular Mass And Gram Formula Mass

- Gram atomic mass represents one mole of atoms of an element, gram molecular mass represents one mole of molecules of a compound or an element that exists in molecular state whereas gram formula mass represents one mole of ionic formula units of a compound.
- Gram atomic mass contains 6.022×10^{23} atoms, gram molecular mass contains 6.022×10^{23} molecules whereas gram formula mass contain 6.022×10^{23} formula units.
- All of these quantities represent molar mass. Mass of one mole of a substance expressed in grams is called molar mass. **“Therefore, mole can be defined as atomic mass, molecular mass or formula mass expressed in grams”.**

1.5 CHEMICAL CALCULATIONS

In this section, you will learn about the chemical calculations based on the concept of mole and Avogadro's number.

1.5.1 Mole-Mass Calculations

Example 1.5: Calculating mass of one mole of a substance

Calculate the molar masses of (a) Na (b) Nitrogen (c) Sucrose $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

Problem solving strategy:

If an element is a metal then its molar mass is its atomic mass expressed in grams (gram atomic mass). If an element exists as molecule, its molar mass is its molecular mass expressed in grams (gram molecular mass).

Solution:

a) 1 mole of Na = 23g

b) Nitrogen occurs as diatomic molecules.

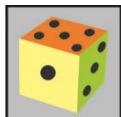
$$\begin{aligned}\text{Molecular mass of N}_2 &= 14 \times 2 \\ &= 28\text{amu}\end{aligned}$$

Therefore, mass of 1 mole of N_2 = 28 g



$$\begin{aligned} \text{c) Molecular mass of } \text{C}_{12}\text{H}_{22}\text{O}_{11} &= 12 \times 12 + 1 \times 22 + 16 \times 11 \\ &= 144 + 22 + 176 \end{aligned}$$

$$\text{Therefore, mass of 1 mole of sucrose} = 342\text{g}$$



Self-Assessment Exercise 1.8

Calculate the mass of one mole of (a) Copper (b) Iodine (c) Potassium (d) Oxygen

Example 1.5(a): Calculating the mass of a given number of moles of a substance

Oxygen is converted to ozone (O_3) during thunder storms. Calculate the mass of ozone if 9.05 moles of ozone is formed in a storm?

Problem solving strategy:

Ozone is a molecular substance. Determine its molar mass and use it to convert moles to mass in grams.

$$9.05 \text{ moles of } \text{O}_3 \longrightarrow ? \text{ g of } \text{O}_3$$

Solution:

$$\begin{aligned} 1 \text{ mole of } \text{O}_3 &= 16 \times 3 \\ &= 48 \text{ g} \end{aligned}$$

$$1 \text{ mole of } \text{O}_3 = 48 \text{ g}$$

$$\begin{aligned} \text{So, } 9.05 \text{ moles of } \text{O}_3 &= 48 \text{ g} \times 9.05 \\ &= 434.4\text{g of } \text{O}_3 \end{aligned}$$

Example 1.6: When natural gas burns CO_2 is formed. If 0.25 moles of CO_2 is formed, what mass of CO_2 is produced?

Problem solving strategy:

Carbon dioxide is a molecular substance. Determine its molar mass and use it to convert moles to mass in grams

$$0.25 \text{ moles of } \text{CO}_2 \longrightarrow ? \text{ g of } \text{CO}_2$$

Solution:

$$\begin{aligned} \text{Molar mass of } \text{CO}_2 &= 12 + 16 \times 2 \\ &= 44\text{g} \end{aligned}$$

$$1 \text{ mole of } \text{CO}_2 = 44\text{g of } \text{CO}_2$$

$$\begin{aligned} \text{So, } 0.25 \text{ moles of } \text{CO}_2 &= 44 \times 0.25 \\ &= 11\text{g of } \text{CO}_2 \end{aligned}$$

**Example 1.7: Converting grams to moles**

How many moles of each of the following substance are present?

- (a) A balloon filled with 5g of hydrogen.
 (b) A block of ice that weighs 100g.

Problem solving strategy:

Hydrogen and ice both are molecular substances. Determine their molar masses. Use the molar mass of each to convert masses in grams to moles.

mass \longrightarrow ? moles

Solution:

- a) Molar mass of H_2 $= 1.008 \times 2$
 $= 2.016g$
 1 mole of H_2 $= 2.016g$
 So, 2.016g of H_2 $= 1$ mole of H_2
 1g of H_2 $= \frac{1}{2.016}$ moles of H_2
 5g of H_2 $= \frac{1}{2.016} \times 5$ moles of H_2
 $= 2.48$ moles of H_2
- b) 1 mole of H_2O $= 2 \times 1.008 + 16$
 $= 2.016 + 16$
 $= 18.016g$
 So, 18.016g of H_2O $= 1$ mole
 1g of H_2O $= \frac{1}{18.016}$ moles
 100g of H_2O $= \frac{1}{18.016} \times 100$ moles
 $= 5.55$ moles of H_2O

**Self-Assessment Exercise 1.9**

- The molecular formula of a compound used for bleaching hair is H_2O_2 . Calculate (a) Mass of this compound that would contain 2.5 moles. (b) No. of moles of this compound that would exactly weigh 30g.
- A spoon of table salt, NaCl contains 12.5grams of this salt. Calculate the number of moles it contains.
- Before the digestive systems X-rayed, people are required to swallow suspensions of barium sulphate $BaSO_4$. Calculate mass of one mole of $BaSO_4$.

**Teacher's Point**

A teacher may encourage students solve self-assessment exercise themselves.



Reading

1.5.2 Mole-Particles Calculations

Example 1.8: Calculating the number of atoms in given moles

1. Zn is a silvery metal that is used to galvanize steel to prevent corrosion. How many atoms are there in 1.25 moles of Zn.
2. A thin foil of aluminium (Al) is used as wrapper in food industries. How many atoms are present in a foil that contains 0.2 moles of aluminium?

Problem solving strategy:

Remember that symbols Zn and Al stand for one mole of Zn and Al atoms respectively.

Solution:

1. 1 mole of Zn contains $= 6.022 \times 10^{23}$ atoms
 1.25 moles of Zn contain $= 6.022 \times 10^{23} \times 1.25$
 $= 7.53 \times 10^{23}$ Zn atoms
2. 1 mole of Al contains $= 6.022 \times 10^{23}$ atoms
 So 0.2 moles of Al will contain $= 6.022 \times 10^{23} \times 0.2$
 $= 1.2044 \times 10^{23}$ atoms

Example 1.9: Calculating the number of molecules in given moles of a substance

1. Methane (CH_4) is the major component of natural gas. How many molecules are present in 0.5 moles of a pure sample of methane?
2. At high temperature hydrogen sulphide (H_2S) gas given off by a volcano is oxidized by air to sulphur dioxide (SO_2). Sulphur dioxide reacts with water to form acid rain. How many molecules are there in 0.25 moles of SO_2 .

Problem solving strategy:

Remember that CH_4 is a molecular compound, thus 1 mole of methane will have 6.022×10^{23} molecules. Similarly, SO_2 is a molecular compound, its one mole will also have 6.022×10^{23} molecules.

Solution:

1. 1 mole of CH_4 contains $= 6.022 \times 10^{23}$ molecules
 So, 0.5 moles of CH_4 will contain $= 6.022 \times 10^{23} \times 0.5$
 $= 3.011 \times 10^{23}$ molecules
2. 1 mole of SO_2 contains $= 6.022 \times 10^{23}$ molecules
 So, 0.25 moles of SO_2 will contain $= 6.022 \times 10^{23} \times 0.25$
 $= 1.5055 \times 10^{23}$ molecules

**Example 1.10: Calculating the number of moles in the given number of atoms**

Titanium is corrosion resistant metal that is used in rockets, aircrafts and jet engines. Calculate the number of moles of this metal in a sample containing 3.011×10^{23} Ti-atoms.

Problem solving strategy:

Remember that 1 mole of an element contains 6.022×10^{23} atoms.

Thus,

$$6.022 \times 10^{23} \text{ atoms} = 1 \text{ mole}$$

$$3.011 \times 10^{23} \text{ atoms} \longrightarrow ? \text{ moles}$$

Solution:

$$6.022 \times 10^{23} \text{ Ti atoms} = 1 \text{ mole of Ti}$$

$$1 \text{ Ti atom} = \frac{1}{6.022 \times 10^{23}} \text{ moles of Ti}$$

$$\begin{aligned} 3.011 \times 10^{23} \text{ Ti atoms} &= \frac{1}{6.022 \times 10^{23}} \times 3.011 \times 10^{23} \text{ moles of Ti} \\ &= 0.5 \text{ moles of Ti} \end{aligned}$$

Example 1.11: Calculating number of moles in the given number of molecules

Formaldehyde is used to preserve dead animals. Its molecular formula is CH_2O . Calculate the number of moles that would contain 3.011×10^{22} molecules of this compound.

Problem Solving Strategy:

Remember that 1 mole of any compound contains 6.022×10^{23} molecules.

Thus,

$$6.022 \times 10^{23} \text{ molecules} = 1 \text{ mole of compound}$$

$$3.011 \times 10^{22} \text{ molecules} \longrightarrow ? \text{ moles}$$

Solution:

$$6.022 \times 10^{23} \text{ molecules} = 1 \text{ mole of formaldehyde}$$

$$1 \text{ molecule} = \frac{1}{6.022 \times 10^{23}} \text{ moles of formaldehyde}$$

$$\begin{aligned} 3.011 \times 10^{22} \text{ molecules} &= \frac{1}{6.022 \times 10^{23}} \times 3.011 \times 10^{22} \text{ moles of formaldehyde} \\ &= 0.05 \text{ moles of formaldehyde} \end{aligned}$$

**Self-Assessment Exercise 1.10**

1. Aspirin is a compound that contains carbon, hydrogen and oxygen. It is used as a painkiller. An aspirin tablet contains 1.25×10^{30} molecules. How many moles of this compound are present in the tablet?
2. A method used to prevent rusting in ships and underground pipelines involves connecting the iron to a block of a more active metal such as magnesium. This method is called cathodic protection. How many moles of magnesium are present in 1 billion (1×10^9) atoms of magnesium.

**Key Points**

- Chemistry is the science of materials of the universe.
- The branch of Chemistry that deals with laws and theories to understand the structure and changes of matter is called Physical Chemistry. Organic chemistry deals with carbon compounds (except bicarbonates carbonates oxides and carbides).
- The branch of Chemistry that deals with elements and their compounds except organic compounds is called Inorganic Chemistry.
- Physical and chemical changes that occur in living organisms are studied in biochemistry.
- Industrial chemistry is concerned with the large scale production of chemical substances.
- An element is a substance all the atoms of which have the same atomic number.
- A compound consists of two or more elements held together in fixed proportions by chemical bonds.
- An impure substance that contains two or more pure substances that retain their individual chemical characteristics is called a mixture.
- The number of protons in the nucleus of an atom is known as its atomic number.
- The total number of protons and neutrons in an atom is called its mass number.
- Atoms of an element that have different number of neutrons are called isotopes.
- The mass of an atom of an element relative to the mass of an atom of C-12 is called relative atomic mass.
- One atomic mass unit is defined as the mass exactly equal to one-twelfth the mass of one C-12 atom.
- Chemical formula of a compound that gives the simplest whole-number ratio between atoms is called empirical formula.
- Molecular formula of a compound gives the exact number of atoms present in a molecule.
- Molecular mass is the sum of atomic masses of all the atoms present in the molecule.
- Positively charged ions are called cations and negatively charged ions are called anions.
- When a molecule loses or gains electrons, the resulting species is called molecular ion.



- Free radical is an atom or group of atoms that contains an unpaired electron.
- The number of representative particles in one mole of the substance is known as Avogadro's number.
- The amount of matter that contains as many atoms, ions or molecules as the number of atoms in exactly 12g of C-12 is called mole. Mole can also be defined as atomic mass, molecular mass or formula mass expressed in grams.
- Atomic mass of an element expressed in grams is called gram atomic mass.
- Molecular mass of an element or a compound expressed in grams is its gram molecular mass.
- Gram formula mass is the formula mass of a substance in grams.

REFERENCES FOR ADDITIONAL INFORMATION

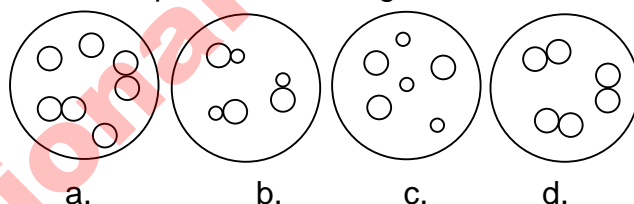
- Zumdahl, Introductory Chemistry.
- Raymond Chang, Essential Chemistry.

**Activity**

Take two balloons. Fill one balloon full of air and other half. Then weigh both and compare the masses of both. It confirms that masses of gases increase with increase in number of molecules in it.

**Review Questions****1. Encircle the correct answer:**

- (i) Which of the following lists contains only elements?
 (a) Air, water, oxygen (b) Hydrogen, oxygen, brass
 (c) Air, water, fire, earth (d) Calcium, sulphur, carbon
- (ii) The diagrams below represent particles in four substances, which box represent the particles in nitrogen.



- (iii) What is the formula mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. (Atomic masses: Cu=63.5, S=32, O=16, H=1)
 (a) 159.5 (b) 185.5 (c) 249.5 (d) 149.5
- (iv) A compound with chemical formula Na_2CX_3 has formula mass 106amu. Atomic mass of the element X is
 (a) 106 (b) 23 (c) 12 (d) 16
- (v) How many moles of molecules are there in 16g oxygen.
 (a) 1 (b) 0.5 (c) 0.1 (d) 0.05
- (vi) What is the mass of 4 moles of hydrogen gas.
 (a) 8.064g (b) 4.032g (c) 1g (d) 1.008g



- (vii) What is the mass of carbon present in 44g of carbon dioxide.
(a) 12g (b) 6g (c) 24g (d) 44g
- (viii) The electron configuration of an element is $1s^2 2s^2$. An atom of this element will form an ion that will have charge.
(a) +1 (b) +2 (c) +3 (d) -1
- (ix) Which term is the same for one mole of oxygen and one mole of water?
(a) volume (b) (c) mass (d) atoms (e) molecules
- (x) If one mole of carbon contains x atoms, what is the number of atoms contained in 12g of Mg.
(a) x (b) $0.5x$ (c) $2x$ (d) $1.5x$

2. Give short answers.

- (i) Differentiate between an ion and a free radical
(ii) What do you know about corpuscular nature of matter?
(iii) Differentiate between analytical chemistry and environmental chemistry.
(iv) What is mole?
(v) Differentiate between empirical formula and molecular formula.
(vi) What is the number of molecules in 9.0 g of steam?
(vii) What are the molar masses of uranium -238 and uranium -235?
(viii) Why one mole of hydrogen molecules and one mole of H-atoms have different masses?

3. Define ion, molecular ion, formula unit, free radical, atomic number, mass number, atomic mass unit.

4. Differentiate between (a) atom and ion (b) molecular ion and free radical.

5. Describe how Avogadro's number is related to a mole of any substance.

6. Calculate the number of moles of each substance in samples with the following masses:

- (a) 2.4 g of He (b) 250mg of carbon (c) 15g of sodium chloride
(d) 40g of sulphur (e) 1.5kg of MgO

7. Calculate the mass in grams of each of the following samples:

- (a) 1.2 moles of K (b) 75moles of H_2 (c) 0.25 moles of steam
(d) 1.05 moles of $CuSO_4 \cdot 5H_2O$ (e) 0.15moles of H_2SO_4

8. Calculate the number of molecules present in each of the following samples:

- (a) 2.5 moles of carbon dioxide (b) 3.4 moles of ammonia, NH_3
(c) 1.09 moles of benzene, C_6H_6 (d) 0.01 moles of acetic acid, CH_3COOH

9. Decide whether or not each of the following is an example of empirical formula:

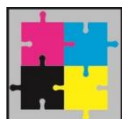
- (a) Al_2Cl_6 (b) Hg_2Cl_2 (c) NaCl (d) C_2H_6O

10. TNT or trinitrotoluene is an explosive compound used in bombs. It contains 7 C-atoms, 5 H-atoms, 3 -N atoms and 6 O-atoms. Write its empirical formula.

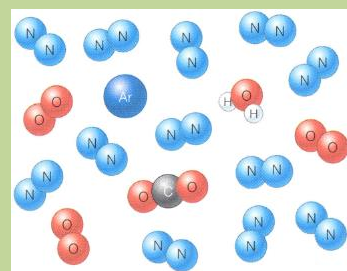
11. A molecule contains four phosphorus atoms and ten oxygen atoms. Write the empirical formula of this compound. Also determine the molar mass of this molecule.



12. Indigo ($\text{C}_{16}\text{H}_{10}\text{N}_2\text{O}_2$), the dye used to colour blue jeans is derived from a compound known as indoxyl ($\text{C}_8\text{H}_7\text{ON}$). Calculate the molar masses of these compounds. Also write their empirical formulas.
13. Identify the substance that has formula mass of 133.5amu.
(a) MgCl_2 (b) S_2Cl_2 (c) BCl_3 (d) AlCl_3
14. Calculate the number of atoms in each of the following samples:
(a) 3.4 moles of nitrogen atoms (b) 23g of Na (d) 5g of H atoms
15. Calculate the mass of the following:
(a) 3.24×10^{18} atoms of iron (b) 2×10^{10} molecules of nitrogen gas
(c) 1×10^{25} molecules of water (d) 3×10^6 atoms of Al
16. Identify the branch of chemistry that deals with the following examples:
1. A cornstalk grows from a seed.
 2. Dynamite ($\text{C}_3\text{H}_5\text{N}_3\text{O}_9$) explodes to form a mixture of gases.
 3. Purple iodine vapour appears when solid iodine is warmed.
 4. Gasoline (a mixture of hydrocarbons) fumes are ignited in an auto mobile engine.
 5. A silver article tarnishes in air.
 6. Ice floats on water.
 7. Sulphur dioxide is the major source of acid rain.
 8. Many other light chlorinated hydrocarbons in drinking water are carcinogens.
 9. In Pakistan most of the factories use wet process for the production of cement.
 10. Carbon-14 is continuously produced in the atmosphere when high energy neutrons from space collide with nitrogen-14.

**Think-Tank**

1. What mass of sodium metal contains the same number of atoms as 12.00g of carbon.
2. What mass of oxygen contains the same number of molecules as 42g of nitrogen.
3. Calculate the mass of one hydrogen atom in grams.
4. Observe the given figure. It shows particles in a sample of air.
 - a) Count the substances shown in the sample
 - b) Is air a mixture or pure substance? Explain?
 - c) Identify the formula of each substance in air.
 - d) Argue whether each substance in air is an element or a compound.
 - e) What is the most common substance in air?
5. Calculate the number of H-atoms present in 18g H_2O .
6. Calculate the total number of atoms present in 18g H_2O .





2

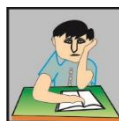
STRUCTURE OF ATOMS



This is a 14 days lesson

After completing this lesson, you will be able to:

- Describe the contribution the Rutherford Atomic Theory in the structure of the atoms.
- Explain how Bohr's Atomic Theory differed from Rutherford's Atomic theory.
- Compare isotopes of an element.
- Describe the structure of an atom including the location of the proton, electron and neutron.
- Describe the contribution that Rutherford made to the development of the atomic theory
- Describe the presence of sub shells in a shell.
- Define isotopes.
- Distinguish between shells and sub shells.
- Discuss the properties of the isotopes of H, C, Cl, U.
- Draw the structures of different isotopes from mass number and atomic number.
- State the importance and uses of isotopes in various fields of life.
- Write the electronic configuration of the first 18 elements in the Periodic Table.



Pre- Reading

The structure of atom tells how the sub-atomic particles are arranged. Atoms are so small that they can only be visualized with a scanning tunneling microscope. See figure 2.1 that shows an image of gold atoms on the surface. In grade VII you have learned about the structure of atom and sub-atomic particles, electrons, protons and neutrons. In this chapter you will learn about the arrangement of these particles in an atom. Atomic structure was formulated from a series of experiments during the later part of nineteenth century and the beginning of the twentieth

century. We will discuss contributions of British physicist Rutherford and Danish physicist Neil Bohr for determining the structure of an atom. Bohr's structure of an atom nicely explains the arrangement of elements in the periodic table and periodicity of properties. How? To understand this you should know the structure of atoms.



Reading

2.1 THEORIES AND EXPERIMENTS RELATED TO ATOMIC STRUCTURE

In grade VII you have learned about the structure of atom and sub-atomic particles. You have also learned the distribution of electrons in shells (KLM only) using $2n^2$ formula. In this section you will learn about theories and experiments related to atomic structure.



2.1.1 Rutherford's Atomic Model

In 1911 Rutherford performed an experiment in order to know the arrangement of electrons and protons in atoms.

2.1.1.1 Rutherford's Experiment

Rutherford bombarded a very thin gold foil about 0.00004cm thickness with α -particles. (figure 2.1). He used α -particles obtained from the disintegration of polonium. α -particles are helium nuclei that are doubly positively charged (He^{++}). Most of these particles passed straight through the foil. Only few particles were slightly deflected. But one in 1 million was deflected through an angle greater than 90° from their straight paths. Rutherford performed a series of experiments using thin foils of other elements. He observed similar results from these experiments.

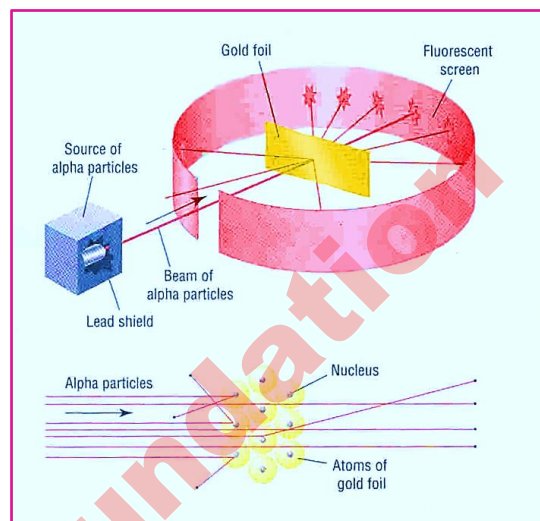


Figure 2.1 Rutherford's Experiment

Rutherford drew the following conclusions:

1. Since majority of the α -particles passed through the foil undeflected, most of the space occupied by an atom must be empty.
2. The deflection of a few α -particles through angles greater than 90° shows that these particles are deflected by electrostatic repulsion between the positively charged α -particles and the positively charged part of atom.
3. Massive α -particles are not deflected by electrons.

On the basis of conclusions drawn from these experiments, Rutherford proposed a new model for an atom. He proposed a planetary model (similar to the solar system) for an atom. An atom is a neutral particle. The mass of an atom is concentrated in a very small dense positively charged region. He named this region as nucleus. The electrons are revolving around the nucleus in circles. These circles are called orbits. The centripetal force due to the revolution of electrons balances the electrostatic force of attraction between the nucleus and the electrons.

2.1.1.2 Defects in Rutherford's Atomic Model

Rutherford's model of an atom resembles our solar system. It has following defects:

1. Classical physics suggests that electron being charged particle will emit energy continuously while revolving around the nucleus. Thus the orbit of the revolving electron becomes smaller and smaller until it would fall into the nucleus. This would collapse the atomic structure.
2. If revolving electron emits energy continuously it should form a continuous spectrum for an atom but a line spectrum is obtained.



Teacher's Point

Tube light is a discharge tube



Bohr formulated new explanation and a new theory to remove defects from the Rutherford's atomic model.

2.1.2 Bohr's Atomic Theory

In 1913 Neil Bohr, proposed a model for an atom that was consistent with Rutherford's model. But it also explains the observed line spectrum of the hydrogen atom. Main postulates of Bohr's atomic theory are as follows:

1. The electron in an atom revolves around the nucleus in one of the circular orbits. Each orbit has a fixed energy. So each orbit is also called energy level.
2. The energy of the electron in an orbit is proportional to its distance from the nucleus. The farther the electron is from the nucleus, the more energy it has.
3. The electron revolves only in those orbits for which the angular momentum of the electron is an integral multiple of $\frac{h}{2\pi}$

where h is Planck's constant (its value is 6.626×10^{-34} J.s).

4. Light is absorbed when an electron jumps to a higher energy orbit and emitted when an electron falls into a lower energy orbit. Electron present in a particular orbit does not radiate energy.
5. The energy of the light emitted is exactly equal to the difference between the energies of the orbits.

Society, Technology and Science

Rutherford was the first scientist who proposed first atomic model of an atom. He suggested that all of the positive charge and most of the mass of the atom is concentrated in the nucleus. The remaining volume of the atom is occupied by electrons that revolve around the nucleus in circles called orbits. These suggestions remained unchallenged. But his model could not explain the stability of an atom and line spectrum for an atom. Bohr leaped over difficulty by using Quantum Theory of Radiation that was proposed by Max Planck. Bohr proposed that an electron moves around the nucleus in well defined circular paths called orbits. An orbit has fixed energy. Electron present in an orbit does not emit energy. Bohr atomic theory explains nicely the stability of an atom and also explains why an atom gives line spectrum. Development of Bohr's atomic model explains how interpretations of experimental results of other scientists help chemists to formulate new explanations and new theories.

$$\Delta E = E_2 - E_1$$

Where ΔE is the energy difference between any two orbits with energies E_1 and E_2

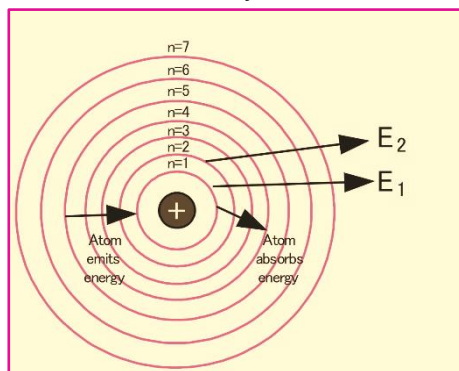


Figure 2.2 Bohr's model of the atom

**Self-Assessment Exercise 2.1**

Draw Bohr's Model for the following atoms indicating the location for electrons, protons and neutrons,

- (a) Carbon (Atomic No. 6, Mass No. 12)
- (b) Chlorine (Atomic No. 17, Mass No. 35)

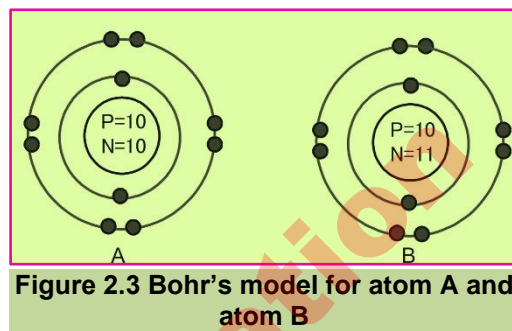
**Reading****2.2 ISOTOPES**

Figure 2.3 shows Bohr's Model for two atoms A and B

Can you identify three similarities and two differences in these atoms?

You will find,

- (a) Both the atoms have same number of protons.
- (b) Both the atoms have same number of electrons.
- (c) Both have same atomic number.
- (d) Both have different number of neutrons.
- (e) Both differ in total number of protons and neutron. This means they have different mass numbers.

Since both the atoms have the same atomic number, they must be the atoms of same element and are called isotopes. The word isotope was first used by Soddy. It is a Greek word "isos" means same and "tope" means place.

Isotopes are atoms of an element whose nuclei have the same atomic number but different mass number. This is because atoms of an element can differ in the number of neutrons. Isotopes are chemically alike and differ in their physical properties.

How does the discovery of isotopes contradicted Dalton's atomic theory?

Isotopes of Hydrogen

Hydrogen has three isotopes. Hydrogen –1 (Protium) has no neutron. Almost all the hydrogen is Hydrogen –1. Its symbol is ${}^1_1\text{H}$. Hydrogen – 2 (deuterium) has one neutron and hydrogen –3 (Tritium) has two neutrons. Their symbols are ${}^2_1\text{H}$ and ${}^3_1\text{H}$ respectively. Because hydrogen –1 also known as protium has only one proton, adding a neutron doubles its mass.

Society, Technology and Science

Dalton's atomic theory explained data from many experiments. So it was widely accepted. Discovery of sub-atomic particles and isotopes proved that some of Dalton's ideas about atoms were not correct. Scientists did not discard his theory. Instead, they revised the theory to take into account new discoveries. This shows how prevailing theories bring about changes in them.



Protium / Hydrogen is a colourless, odourless, and tasteless gas. It is insoluble in water and is highly inflammable gas. Water that contain hydrogen-2 atoms in place of hydrogen-1 is called heavy water. Table 2.1 Shows some physical properties of ordinary water and heavy water.

Table 2.1 - Comparison of ordinary water and heavy water.

Property	Ordinary water	Heavy water
Melting Point	0.00°C	3.81°C
Boiling point	100°C	101.2°C
Density at 25°C	0.99701 g/cm ³	1.1044 g/cm ³

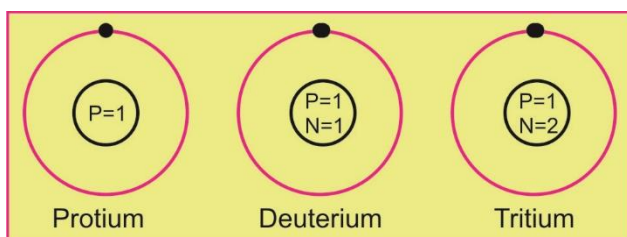


Figure 2.5 Isotopes of hydrogen

At what temperature would a sample of heavy water freeze?

Naturally occurring hydrogen contains 99.99% protium, 0.0015% Deuterium. Tritium is radioactive and is rare. Tritium is not found in naturally occurring hydrogen because its nucleus is unstable.

Isotopes of Carbon

Carbon has three isotopes. Carbon-12, carbon-13 and carbon -14. Almost all the carbon is carbon-12. Its symbol is $^{12}_6\text{C}$. It has six neutrons and six protons. Carbon-13 has symbol $^{13}_6\text{C}$. It has seven neutrons and six protons. Carbon-14 has eight neutrons and six protons. Its symbol is $^{14}_6\text{C}$. Different forms of carbon are black or greyish black solids except diamond. They are odourless and tasteless. They have high melting and boiling points and are insoluble in water.



Activity 2.1

Carbon has three isotopes $^{12}_6\text{C}$, $^{13}_6\text{C}$, $^{14}_6\text{C}$ Figure 2.6 shows incomplete structure of isotopes of carbon. Can you complete it?

Natural abundance of isotopes of carbon is as follows

$$^{12}_6\text{C} = 98.8\%, \quad ^{13}_6\text{C} = 1.1\%, \quad ^{14}_6\text{C} = 0.009\%$$

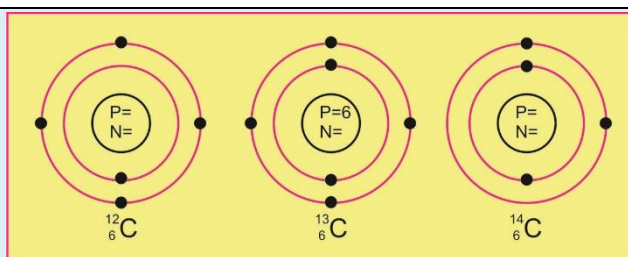


Figure 2.6 Isotopes of Carbon

Isotopes of Chlorine

There are two natural isotopes of chlorine, chlorine-35 and chlorine-37. An atom of chlorine-35 has 17 protons and 18 neutrons. An atom of chlorine-37 has 17 protons and 20 neutrons. Chlorine-35 occurs in nature about 75% and chlorine-37 about 25%. Chlorine is a greyish yellow gas with sharp pungent irritating smell. It is fairly soluble in water.

**Activity 2.2**

Chlorine has two isotopes. Figure 2.7 shows the structure of isotopes of chlorine. Can you write isotope symbol for each?

Isotope symbols: _____
 Natural abundance 75.77% 24.23%

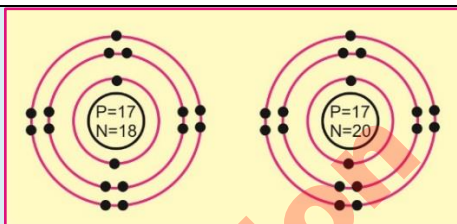
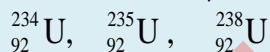


Figure 2.7 Isotopes of chlorine

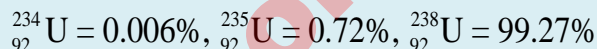
Isotopes of Uranium

**Activity 2.3**

Uranium has three isotopes with mass number 234, 235 and 238 respectively.



The ${}_{92}^{235}\text{U}$ isotope is used in nuclear reactors and atomic bombs, whereas the ${}_{92}^{238}\text{U}$ isotope lacks the properties necessary for these applications. ${}_{92}^{234}\text{U}$ is rare. Natural abundance of Uranium isotopes is as follows:



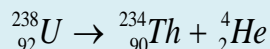
Fill in the blanks?

${}_{92}^{234}\text{U}$ has _____ protons, _____ electrons and _____ neutrons

${}_{92}^{235}\text{U}$ has _____ protons, _____ electrons and _____ neutrons

${}_{92}^{238}\text{U}$ has _____ protons, _____ electrons and _____ neutrons

When uranium-238 decays into thorium-234, it emits alpha particle. An alpha particle is doubly positively charged helium nucleus.



The fission of uranium-235 yields smaller nuclei, neutron and energy. The nuclear energy released by the fission of one kilogram of uranium-235 is equivalent to chemical energy produced by burning more than 17000 kg of coal.

Chemical properties of an element depend upon the number of protons and electrons. Neutrons do not take part in ordinary chemical reactions. Therefore, isotopes of an element have similar chemical properties.

2.2.2 Uses of Isotopes

Stable and radioactive isotopes have many applications in science and medicines. Some of these are as follows:

- (i) Radioactive iodine -131 is used as a tracer in diagnosing thyroid problem.



- (ii) Na-24 is used to trace the flow of blood and detect possible constrictions or obstructions in the circulatory system.
- (iii) Iodine-123 is used to image the brain.

Important information

Carbon-14 is used to estimate the age of carbon-containing substances. Carbon atoms circulate between the oceans, and living organism at a rate very much faster than they decay. As a result the concentration of C-14 in all living things keep on increasing. After death organisms no longer pick up C-14. By comparing the activity of a sample of skull or jaw bones, with the activity of living tissues, we can estimate how long it has been since the organism died. This process is called dating.

- (iv) Cobalt-60 is commonly used to irradiate cancer cells in the hope of killing or shrinking the tumors.
- (v) Carbon-14 is used to trace the path of carbon in photosynthesis.
- (vi) Radioactive isotopes are used to determine the molecular structure e.g. sulphur-35 has been used in the structure determination of thiosulphate, $\text{S}_2\text{O}_3^{-2}$ ion.
- (vii) Radioactive isotopes are also used to study the mechanism of chemical reactions.
- (viii) Radioactive isotopes are used to date rocks, soils, archaeological objects, and mummies.

2.3 ELECTRONIC CONFIGURATION

To understand electronic configuration, you should know about shells and sub-shells.

2.3.1 Shells

According to Bohr's atomic theory, the electron in an atom revolves around the nucleus in one of the circular paths called shells or orbits. Each shell has a fixed energy. So each shell is also called energy level. Each shell is described by an n value. n can have values 1,2,3.....

When,

$n = 1$, it is K shell

$n = 2$, it is L shell

$n = 3$, it is M shell etc.

As the value of n increases the distance of electron from the nucleus and energy of the shell increases.

2.3.2 Sub-Shells

A shell or energy level is sub divided into sub-shells or sub-energy levels. n value of a shell is placed before the symbol for a sub-shell. For instance

$n = 1$, for K shell. It has only one sub-shell which is represented by 1s.

For L shell $n = 2$, L shell has two sub-shells, these are designated as 2s and 2p.

For M shell $n = 3$ So M shell has 3 sub-shells called 3s, 3p and 3d. While N shell has 4s, 4p, 4d and 4f sub-shells.

s sub-shell can accommodate maximum 2 electrons.

p sub-shell can accommodate maximum 6 electrons.



d sub-shell can accommodate maximum 10 electrons.

f sub-shell can accommodate maximum 14 electrons.

The increasing order of energy of the sub-shells belonging to different shells is given below.

$$1s < 2s < 2p < 3s < 3p < 4s < 3d \dots$$

The arrangement of electrons in sub-shells is called as the electronic configuration.

We can fill the electrons present in various elements by using Auf Bau Principle. **According to this principle, electrons fill the lowest energy sub-shell that is available first.** This means electron will fill first 1s, then 2s, then 2p and so on.

2.3.3 Electronic Configuration of First 18 Elements.

Electronic configuration is the distribution of electrons among the different sub-shells of an atom. We can do this by listing the symbol for the occupied sub-shells one after another. Show the number of electrons in the sub-shell as a superscript to each symbol. Because the energies of sub-shells increase in the order, 1s, 2s, 2p, 3s, 3p (as indicated in section 2.2.1), the first five sub-shells fill in that order. Hydrogen has atomic number 1. So it has only one electron that will occupy lowest energy sub-shell 1s. The electronic configuration of H is $1s^1$.

Helium has atomic number 2, so it has two electrons. Since s sub-shell can accommodate two electrons, so electronic configuration of He is $1s^2$.

Lithium has atomic number 3, so it has three electrons, two will fill 1s sub-shell and one 2s sub-shell. So electronic configuration of Li is $1s^2 2s^1$.

Beryllium has atomic number 4, so it has four electrons. Two of these electrons go into 1s sub-shell and two will go to 2s sub-shell. Thus electronic configuration of Be is $1s^2 2s^2$.

Once 2s sub-shell is filled, the 2p sub-shell begins to fill. 2p sub-shell can hold maximum 6 electrons. So next six elements will have configuration in which 2p sub-shell will be progressively filled. Therefore, these elements will have following electronic configuration.

$${}_5\text{B} = 1s^2 2s^2 2p^1$$

$${}_6\text{C} = 1s^2 2s^2 2p^2$$

$${}_7\text{N} = 1s^2 2s^2 2p^3$$

$${}_8\text{O} = 1s^2 2s^2 2p^4$$

$${}_9\text{F} = 1s^2 2s^2 2p^5$$

$${}_{10}\text{Ne} = 1s^2 2s^2 2p^6$$

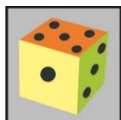
After 2p has completely filled, the additional electrons will fill 3s sub-shell, so electronic configuration of Na & Mg would be

$${}_{11}\text{Na} = 1s^2 2s^2 2p^6 3s^1$$

$${}_{12}\text{Mg} = 1s^2 2s^2 2p^6 3s^2$$



After 3s has completely filled 3p sub-shell begins to fill. So next six elements have electronic configuration by filling 3p sub-shell.



Self-Assessment Exercise 2.3

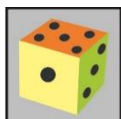
Write the complete electronic configuration for the following elements;

- Al (atomic number 13)
 Si (atomic number 14)
 P (atomic number 15)
 S (atomic number 16)
 Cl (atomic number 17)
 Ar (atomic number 18)

Figure 2.10 shows the electronic configuration in the sub-shell last occupied for the first eighteen elements.

H 1s ¹							He 1s ²
Li 2s ¹	Be 2s ²	B 2s ² 2p ¹	C 2s ² 2p ²	N 2s ² 2p ³	O 2s ² 2p ⁴	F 2s ² 2p ⁵	Ne 2s ² 2p ⁶
Na 3s ¹	Mg 3s ²	Al 3s ² 3p ¹	Si 3s ² 3p ²	P 3s ² 3p ³	S 3s ² 3p ⁴	Cl 3s ² 3p ⁵	Ar 3s ² 3p ⁶

Figure 2.10 Valence shell configuration of first 18 elements



Self-Assessment Exercise 2.4

Write the electronic configuration for the following isotopes

- (a) ${}^{14}_6\text{C}$, (b) ${}^{35}_{17}\text{Cl}$, (c) ${}^{37}_{17}\text{Cl}$



Key Points

- Rutherford proposed a planetary model for an atom. The nucleus of an atom is composed of protons. The electrons surround the nucleus and occupy most of the volume of the atom.
- According to Bohr's atomic model, the electron in an atom revolves around the nucleus in fixed circular orbits called shells. Energy is absorbed when an electron jumps to a higher energy orbit and emitted when an electron falls into a lower energy orbit.



- Isotopes are atoms of an element that differ in the number of neutrons.
- $^{235}_{92}\text{U}$ isotope is used in nuclear reactors and atomic bombs.
- Radioactive isotopes have many applications in science and medicines such as killing cancer cells, diagnosing thyroid problem, to image the brain, to detect obstruction in the circulatory system, to date rocks, soils, mummies etc.
- A shell or energy level is divided into sub-shells.
- The arrangement of electrons in sub-shells is called as the electronic configuration.
- According to the Auf Bau Principle, electrons fill the lowest energy levels first.

REFERENCES FOR ADDITIONAL INFORMATION

- B.Earl and LDR Wilford, Introduction to Advanced Chemistry.
- Iain Brand and Richard Grime, Chemistry (11-14).



Review Questions

1. Encircle the correct answer:

- According to Bohr atomic model:
 - Each orbit has fixed energy, so each orbit is called sub-energy level.
 - The energy of the electron is inversely proportional to its distance from the nucleus.
 - Light is absorbed when an electron jumps a lower energy orbit.
 - The further the electron is from the nucleus, the more energy it has.
- Chlorine has two isotopes, both of which have
 - same mass number.
 - same number of neutrons.
 - different number of protons.
 - same number of electrons.
- Number of neutrons in $^{27}_{13}\text{M}$ are
 - 13
 - 14
 - 27
 - 15
- Which isotope is commonly used to irradiate cancer cells?
 - Iodine-123
 - Carbon-14
 - Cobalt-60
 - Iodine-131
- M shell has sub-shells:
 - 1s, 2s
 - 2s, 2p
 - 3s, 3p, 3d
 - 1s, 2s, 3s
- A sub-shell that can accommodate 6 electrons is
 - s
 - d
 - p
 - f
- $_{11}\text{Na}$ has electronic configuration:
 - $1s^2 2s^2 3s^1$
 - $1s^2 2s^2 2p^7$
 - $1s^2 2s^2 2p^5 3s^2$
 - $1s^2 2s^2 2p^6 3s^1$
- Rutherford used _____ particles in his experiments.
 - He atoms
 - He^+
 - He^{+2}
 - He^{-2}

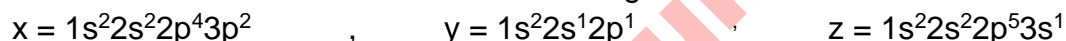


- (ix) Which of the following statement is not correct about isotopes?
 (a) they have same atomic number (b) they have same number of protons
 (c) they have same chemical properties (d) they have same physical properties
- (x) Which isotope is used in nuclear reactors?
 (a) U-234 (b) U-238 (c) U-235 (d) All of these

2. Give short answers

- Distinguish between shell and sub-shell
- Why an atom is electrically neutral?
- How many sub-shells are there in N shell.
- Give notation for sub-shells of M shell.
- List the sub-shells of M Shell in order of increasing energy
- Can you identify an atom without knowing number of neutrons in it?

3. The electronic configurations listed are incorrect. Explain what mistake have been made in each and write correct electronic configurations.



4. Which orbital in each of the following pairs is lower in energy?

- (a) 2s, 2p (b) 3p, 2p (c) 3s, 4s

5. Draw Bohr's Model for the following atoms indicating the location for electron, protons and neutrons:

- (a) Potassium (Atomic No 19, Mass No. 39) (b) Silicon (Atomic No. 14 Mass No. 28)
 (c) Argon (Atomic No. 18 Mass No. 39)

6. Write electronic configuration for the following elements:

- (a) ${}_{14}^{28}\text{Si}$ (b) ${}_{12}^{24}\text{Mg}$ (c) ${}_{13}^{27}\text{Al}$ (d) ${}_{18}^{40}\text{Ar}$

- Describe the contribution that Rutherford made to the development of the atomic theory.
- Explain how Bohr's atomic theory differed from Rutherford's atomic theory.
- Describe the presence of sub shells in a shell.
- State the importance and uses of isotopes in various fields of life.
- The atomic number of an element is 23 and its mass number is 56.
 - How many protons and electrons does an atom of this element have?
 - How many neutrons does this atom have?
- The atomic symbol of aluminum is written as ${}_{13}^{27}\text{Al}$. What information do you get from it?
- How the prevailing theories about testing bring changes in atomic theories?
- How experimental results of some scientists help chemist to formulate new theories and new explanation.

**Think-Tank**

15. M-24 is a radioactive isotope used to diagnose restricted blood circulation, for example in legs. How many electrons, protons and neutrons are there in this isotope. Valence shell electronic configuration of M is $3s^1$.
16. Two isotopes of chlorine are $^{35}_{17}\text{Cl}$ and $^{37}_{17}\text{Cl}$. How do these isotopes differ? How are they alike?
17. How many electrons can be placed in all of the sub-Shells in the $n=2$ shell?
18. Mass number of an atom indicates total number of protons and neutrons in the nucleus. Can you identify an atom without any neutron?
19. The table shows the nuclei of five different atoms.

Name of atom	Number of Protons	Number of neutrons
A	5	6
B	6	6
C	6	7
D	7	7
E	8	8

- Which atom has the highest mass number?
 - Which two atoms are isotopes?
 - Which atom has the least number of electrons?
 - Which atom will have electronic configuration $1s^2 2s^2 2p^3$.
 - Which of the atom contains the most number of electrons?
20. Naturally occurring nitrogen has two isotopes N-14 and N-15 select isotope that has greater number of electrons.



3

PERIODIC TABLE AND PERIODICITY OF PROPERTIES



This is a 20 days lesson

After completing this lesson, you will be able to:

- Classify the element (into two categories: groups and periods) according to the configuration of their outer most shell.
- Distinguish between a period and a group in the periodic table. (Understanding)
- State the periodic law.
- Determine the demarcation of the periodic table into an s block and p block.
- Determine the location of families in the periodic table. Recognize the similarity in the chemical and physical properties of elements in the same family of elements.
- Describe how electronegativities change within a group and within a period in the periodic table.
- Explain the shape of the periodic table.
- Explain how shielding effect influences periodic trends.
- Identify the relationship between electronic configuration and the position of an element in the periodic table.



Pre- Reading

By the end of 18th century, 23 elements were known, by 1870, 65, by 1925, 88, today there are 109. These elements combine to form millions of compounds. It is very difficult rather impossible to remember information concerning reactions, properties and atomic masses of elements. So we clearly need some way to organize our knowledge about them.

The periodic table is one of the most important tools in chemistry. It is very useful for understanding and predicting the properties of elements. For instance if you know physical and

chemical properties of one element in a group, you can predict about the physical and chemical properties of any other element present in the same group. You can use periodic table to relate trends in the reactivity of elements with their atomic structure. You can also predict which elements can form ionic or covalent bonds.



Reading

3.1 PERIODIC TABLE

One of the most important activities is the search for order. A large number of observations or objects can be arranged into groups according to common features they share,



it becomes easier to describe them. After the discovery of atomic number by Moseley in 1913, it was noticed that atomic number could serve as a base for systematic arrangement of elements. Thus elements are arranged in the order of increasing atomic number. A table showing systematic arrangement of elements is called periodic table. It is based on the Periodic law that states **if the elements are arranged in the order of their increasing atomic numbers, their properties are repeated in a periodic manner.**

3.1.1 Periods and Groups of Elements.

The most commonly used form of the periodic table is shown in figure 3.1. Note that the elements are listed in order of increasing atomic numbers, from left to right and from top to bottom. Hydrogen (H) is in the top left corner. Helium (He), atomic number 2, is at the top right corner. Lithium (Li), atomic number 3, is at the left end of the second row.

The horizontal rows of the periodic table are called periods. There are varying number of elements in periods. How many periods you find in the periodic table? There are seven periods. The number of elements per period range from 2 in period 1 to 32 in period 6. First three periods are called **short periods** and the remaining periods are called **long periods**. The properties of elements within a period change gradually as you move from left to right in it. But when you move from one period to the next, the pattern of properties within a period repeats. This is in accordance to the periodic law.



Activity 3.1

Look at the periodic table and write number of elements present in the relevant period in the table 3.1

Table 3.1 Number of elements in the periods of the periodic table

Period No.	No. of elements
First	
Second	
Third	
Fourth	
Fifth	
Sixth	
Seventh	



Teacher's Point

Teacher may ask students to memorise elements of 1st two groups and 1st two periods.



Figure 3.1: Periodic Table of Elements

Representative Elements (s Series)

Representative Elements (p Series)

Transition Metals (d Series of Transition Elements)

Inner Transition Elements (f Series)

Lanthanides

Actinides

Period number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1s H 1.0079																	He 4.0026
2	1s Li 6.941	2s Be 9.0122																Ne 20.179
3	1s Na 22.989	2s Mg 24.305	3s Al 13.003	3p Si 28.086	3d P 30.9738	3p S 32.064	3d Cl 35.453	3p Ar 39.948										
4	1s K 39.098	2s Ca 40.08	3s Sc 44.956	3p Ti 47.90	3d V 50.942	3d Cr 51.996	3d Mn 54.938	3d Fe 55.847	3d Co 58.933	3d Ni 58.71	3d Cu 63.546	3d Zn 65.38	3d Ga 69.723	3d Ge 72.59	3d As 74.922	3d Se 78.96	3d Br 79.904	3d Kr 83.80
5	1s Rb 85.468	2s Sr 87.62	3s Y 88.905	3p Zr 91.22	3d Nb 92.906	3d Mo 95.94	3d Tc (99)	3d Ru 101.07	3d Rh 102.905	3d Pd 106.4	3d Ag 107.868	3d Cd 112.40	3d In 114.82	3d Sn 118.69	3d Sb 121.75	3d Te 127.60	3d I 126.904	3d Xe 131.30
6	1s Cs 132.905	2s Ba 137.34	3s La 138.91	3p Hf 178.49	3d Ta 180.948	3d W 183.85	3d Re 186.2	3d Os 190.2	3d Ir 192.2	3d Pt 195.09	3d Au 196.967	3d Hg 200.59	3d Tl 204.37	3d Pb 207.19	3d Bi 208.980	3d Po (209)	3d At (210)	3d Rn (222)
7	1s Fr (223)	2s Ra (226)	3s Ac (227)	3p Unq (261)	3d Unp (262)	3d Unh (263)	3d Uns (264)	3d Uno (265)	3d Uue (266)	3d Uuh (267)	3d Uus (268)	3d Uuo (269)	3d Uuq (270)	3d Uur (271)	3d Uus (272)	3d Uuo (273)	3d Uuq (274)	3d Uur (275)

Key

Period number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1s H 1.0079																	He 4.0026
2	1s Li 6.941	2s Be 9.0122																Ne 20.179
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5	1s Rb 85.468	2s Sr 87.62	3s Y 88.905	3p Zr 91.22	3d Nb 92.906	3d Mo 95.94	3d Tc (99)	3d Ru 101.07	3d Rh 102.905	3d Pd 106.4	3d Ag 107.868	3d Cd 112.40	3d In 114.82	3d Sn 118.69	3d Sb 121.75	3d Te 127.60	3d I 126.904	3d Xe 131.30
6	1s Cs 132.905	2s Ba 137.34	3s La 138.91	3p Hf 178.49	3d Ta 180.948	3d W 183.85	3d Re 186.2	3d Os 190.2	3d Ir 192.2	3d Pt 195.09	3d Au 196.967	3d Hg 200.59	3d Tl 204.37	3d Pb 207.19	3d Bi 208.980	3d Po (209)	3d At (210)	3d Rn (222)
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Transition Metals (d Series of Transition Elements)

Inner Transition Elements (f Series)

Lanthanides

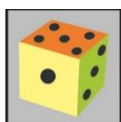
Actinides



Elements that have similar properties lie in the same column in the periodic table. **Each vertical column of elements in the periodic table is called a group or family.**

Elements with similar valance shell electronic configuration are placed in the same group. Each group is identified by a number and the letter A or B. Group A elements are called **normal** or **representative elements**. They are also called main group elements. Group B elements are called **transition elements**.

Some groups of elements in the periodic table have been given group names. For example metallic elements in Group 1A are called **alkali metals**. Group IIA elements are called **alkaline earth metals**. The elements in Group VIIA are **halogens**. The Group VIIIA elements are called **noble gases** because they do not readily undergo chemical reactions.



Self-Assessment Exercise 3.1

In which period and group the following elements are present in the periodic table. (a) Mg
(b) Ne (c) Si (d) B

Example 3.1: Identifying the group and period of an element

Identify the group and period of ${}_{13}^{27}\text{Al}$, ${}_{5}^9\text{B}$, ${}_{12}^{24}\text{Mg}$ on the basis of electronic configuration.

Problem Solving Strategy:

Write electronic configuration of element. Identify its valence shell. Remember that n value of the valence shell indicates period. Total number of electrons in the valence shells represents group number.

Solution:

$$\text{a) } {}_{13}^{27}\text{Al} = \frac{1s^2}{K} \quad \frac{2s^2, 2p^6}{L} \quad \frac{3s^2, 3p^1}{M} \qquad \begin{matrix} K & L & M \\ 1 & 2 & 3 \end{matrix}$$

Valence shells is M

As $n = 3$, Al is present in the 3rd period. Since total number of electrons in the valence sub-shells are $2+1=3$, it must be present in Group IIIA.

Society, Technology, Science

In 1864, John Newland, an English chemist arranged 24 elements in order of increasing atomic masses. He noticed that every eighth element, starting from any point, has similar properties. Few rows of his arrangement are shown below:

H	Li	Be	B	C	N	O
F	Na	Mg	Al	Si	P	S
Cl	K	Ca	Cr	Ti	Mn	Fe

His scheme however, failed because many elements were found out of place in his arrangement. For instance Ti does not resemble C and Si, Mn does not resemble N and P and Fe does not resemble O and S. However his arrangement of elements in order of increasing atomic masses formed basis for later classification of elements.

In 1869, Mendeleev, a Russian chemist developed a classification scheme of elements. He recognized that if elements were placed in order of increasing atomic masses, the properties of elements repeated at regular intervals. He arranged 65 elements in periods and groups. Development of the periodic table nicely explains how scientist can build on one another's work.



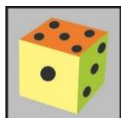
Valence shell is L

So $n = 2$, B is present in the 2nd period. Since total number of electrons in the valence shell are $2+1=3$, it must be present in Group IIIA.



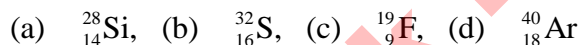
Valence shell is M

So $n = 3$, Mg is present in the 3rd period. Since total number of electrons in the valence shell are 2, it must be present in Group IIA.



Self-Assessment Exercise 3.2

Identify the group and period of the following elements on the basis of electronic configurations.



Example 3.2: Classifying or dividing elements into groups and periods

Electronic configuration of atoms of some elements are given below. Classify them in groups and periods.

- A. $1s^2 2s^2$
- B. $1s^2 2s^2 2p^3$
- C. $1s^2 2s^2 2p^5$
- D. $1s^2 2s^2 2p^6 3s^2$
- E. $1s^2 2s^2 2p^6 3s^2 3p^5$
- F. $1s^2 2s^2 2p^6 3s^2 3p^3$

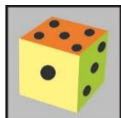
Problem solving Strategy:

Remember that:

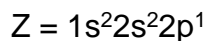
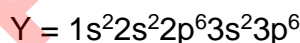
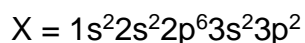
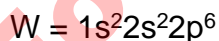
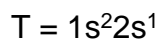
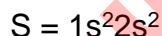
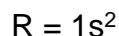
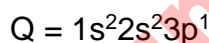
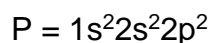
1. The elements whose atoms have similar valence shell electronic configuration belong to the same group.
2. The n value of the valence shell indicates period.
3. The elements whose atoms have same value of n for the valence shell lie in the same period.

**Solution:**

		IIA	VA	VIIA
Period	2	A $2s^2$	B $2s^2 2p^3$	C $2s^2 2p^5$
Period	3	D $3s^2$	F $3s^2 3p^3$	E $3s^2 3p^5$

**Self-Assessment Exercise 3.3**

Electronic configuration of atoms of some elements are given below. Place them into groups and periods.



IA		IIA		IIIA	IVA	VA	VIA	VIIA	VIIIA

3.1.5 s and p Blocks in the Periodic Table

On the basis of outer most valence sub shell, elements in the periodic table can also be classified into four blocks. Elements of Group IA and Group IIA contain their valence electrons in s sub-shell. Therefore, these elements are called **s-block** elements. The elements of Group IIIA to VIIA (except He) are known as **p-block** elements, because their valence electrons lie in p sub-shell. Figure 3.2 shows blocks in the periodic table



3.1.6 Valence Shell Electronic Configuration and Position of an Element in the Periodic Table

You can determine the valence shell electronic configuration of an element from its position in the periodic table. Period number of element indicates n value of the valence shell. Whereas group number of element indicates the number of electrons in the valence shell.

Example 3.3: Obtaining the valence shell configuration

Write the valence shell electronic configuration of the following elements from their position in the periodic table.

- (a) Phosphorus (b) Neon

Problem Solving Strategy:

Remember that

Period number = n value of valence shell

Group number = number of valence electrons

Distribute the electron in the sub-shells of valence shell.

Solution:

- a) Period number of phosphorus is 3,

As $n = 3$ therefore, valence shell is M

So valence electrons will be present in 3s and 3p sub-shells

The group number is 5, so there are 5 electrons in the valence shell

Two electrons will fill 3s sub-shell and remaining 3p sub-shell. Thus, the valence shell electronic configuration is $3s^2 3p^3$

- b) Period number of Ne is 2. So, $n = 2$ and valence shell is L. Valence electrons will be present in 2s and 2p sub-shells.

Group number for Ne is 8,

This means there are 8 electrons in the valence shell. Two electrons will fill 2s sub-shell and remaining six 2p sub-shell. Thus the valence shell electronic configuration for Ne is $2s^2 2p^6$.

Example 3.4: Obtaining the position of element in the periodic table from electronic configuration

Find out the position of the following elements in the periodic table from the electronic configuration:

- (a) Nitrogen (atomic number: 7) (b) Oxygen (atomic number: 8)





Teacher's Point

A teacher may ask student to draw Valence shells electronic configuration of some common elements.

Figure 3.2: Blocks in the periodic table

Period																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
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 Metal
 Metalloid
 Nonmetal



Problem Solving Strategy:

Write electronic configuration of the element. Identify the valence shell configuration, coefficient of s or p sub-shell represents period number and total number of electrons in valence shell is equal to the group number.

Solution:

- a) Electronic configuration of N = $1s^2 2s^2 2p^3$
 Valence shell has configuration = $2s^2 2p^3$
 Period number = 2
 Group number = 2 + 3 = 5
 \therefore Nitrogen is present in the 2nd period of Group V-A
- b) Electronic configuration of oxygen = $1s^2 2s^2 2p^4$
 Valence shell has configuration = $2s^2 2p^4$
 So, Period number = 2
 Group number = 2 + 4 = 6
 \therefore Oxygen is present in the 2nd period of Group VI-A



Self-Assessment Exercise 3.4

1. Obtain the valence shell configuration of Al and S from their position in the periodic table.
2. Find out the position of Ne (At. No 10) and Cl (At. No. 17) in the periodic table.

3.1.7 Shape of the Periodic Table

Recall that the horizontal rows in the periodic table are called periods. How are these periods formed?

Elements are arranged in order of increasing atomic number. First period contains only two elements, H and He. Both these elements have valence electron in K shell. K shell can not have more than two electrons. As K shell is completed at He, so the period also ends at He, Lithium (Li) atomic number 3 has one electron in L shell, so second period begins with Li. Since L shell can accommodate 8 electrons, so eight elements come in the 2nd period. Second period ends at Ne which has eight electron, in L shell ($2s^2 2p^6$).

Next elements Na has valence electron in the third shell (M – shell), in Na valence electron is present, in 3s sub – shell, which has similar electronic configuration as Li ($2s^1$), So it comes under Li. Mg with $3s^2$ valence shell electronic configuration come under Be ($2s^2$), Similarly next six elements Al, Si, P, S, Cl and Ar on the bases of similar valence shell electronic configuration come under B, C, N, O, F, and Ne respectively. Ar has $3s^2 3p^6$ valence shell configuration similar to Ne ($2s^2 2p^6$). Next element K has $4s^1$ electronic configuration in the valence shell, which is similar to Na ($3s^1$). So K comes under Na and a new period (4th) begins with K. In this way elements having similar valence shell configuration come in the same group. The arrangement of the elements into periods has an important consequence. The elements that have similar properties end up in the same group in the periodic table.



3.2 PERIODICITY OF PROPERTIES

In section 3.1.4 you learned that, the electronic configuration of elements show a periodic variation with the increasing atomic number. Therefore, the elements also show periodic variation in their physical and chemical properties. Elements having similar valence shell electronic configuration have been placed in the same group, one below the other. Chemical properties depend on the valence shell electronic configuration. Because all the elements of a particular group have similar valence shell electronic configuration, they possess similar chemical characteristics. Physical properties depend on the sizes of atoms. Since sizes of atoms change gradually from top to bottom in a group. Therefore, elements show gradation in physical properties in the same group. In a period of periodic table the number of electrons present in the valence shell increase gradually from left to right. Their chemical and physical properties also show variation in the same manner. In this section you will learn variation in some of the physical properties of elements in a group and across a period.

3.2.1 Shielding Effect

Figure 3.2 shows electronic configuration of Li, Be and Mg.

Which atom has more shells, Be or Mg? Which atom has more electrons between the nucleus and the valence electrons, Be or Mg?

Electrons present in the inner shells cut off attractive force between the nucleus and the valence electrons.

The reduction in force of attraction between nucleus and the valence electrons by the electrons present in the inner sub-shells is called shielding effect.

Which atom has greater shielding effect, Be or Mg?

As you move from top to bottom in a group the number of electronic shells increase. So the number of electrons in the inner shell also increase. As a result shielding effect increases.

Which atom, Li or Be has greater number of shells? Which atom, Li or Be has greater number of electrons between nucleus and valence electrons?

As you move from left to right in a period the number of electrons in the inner shells remains constant, therefore, shielding effect remains constant.

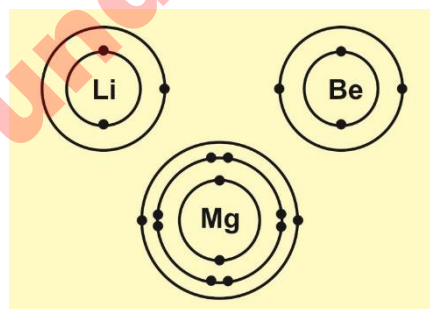


Fig 3.2 Electronic structure of Li, Be and Mg

Example 3.5: Identifying the element whose atoms have greater shielding effect, using periodic table

Choose the elements whose atoms you expect to have greater shielding effect.

(a) Be or Mg

(b) C or Si



Teacher's Point

A teacher may ask student to draw shell of first four elements group A to show shielding effect.

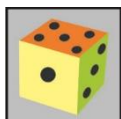


Problem Solving Strategy:

Look at the periodic table and find the relative position of given elements in the periodic table. Apply the trend of increasing shielding effect in a group.

Solution:

- (a) Mg atoms will have greater shielding effect.
- (b) Si atoms will have greater shielding effect.



Self-Assessment Exercise 3.5

Choose the element whose atoms you expect to have smaller shielding effect.

- (a) F or Cl
- (b) Li or Na
- (c) B or Al

All the physical and chemical properties of the elements depend on the electronic configurations of their atoms. Now we will discuss four properties of atoms that are influenced by the electronic configuration: atomic size, ionization energy, electron affinity and electronegativity. These properties are periodic. They generally increase and decrease in a recurring or repeating manner through the periodic table. This means they show consistent changes or trends, within a group or a period. These trends correlate with the behaviour.

3.2.2 Atomic Size

The size of an atom depends on its electronic configuration. **The size of an atom is the average distance between the nucleus of an atom and the outer electronic shell.** Figure 3.3 shows atomic radii of the main group elements.

Figure 3.3 shows the variation in atomic radii in a period and within a group. You can see two general trends in atomic radii.

- (1) The atomic radius decreases in any given period as you move across the period. This is because as you move from one element to the next on its right in a period. Another electron is added to the same valence shell. At the same time positive charge on the nucleus also increases by 1. The attractive force of the nucleus for the valence shell electron increases. Therefore, the shell size and atomic radius decreases. For example, in going from lithium to beryllium, atomic size decreases. This you can understand from the valence shell electronic configuration of Li ($2s^1$) and B ($2s^2$). In going from Li to Be, there is no change in the shell number n , but atomic number increases from 3 to 4. Due to this the force of the nucleus for the valence shell electron increases. Therefore, atomic radius decreases.

The atomic radius increases in any given main group as you move down the group of elements. This is because the size of an atom is determined by the size of its valence shell. As you move to the next lower element in the group, the atom has an additional shell of electrons. This increases atomic radius. For example, in going from Li to Na atomic radius increases.



Period	I-A		II-A		III-A	IV-A	V-A	VI-A	VII-A	VIII-A
	1	H 37 •								He 31 •
	2	Li 152 ●	Be 112 ●		B 85 ●	C 77 ●	N 75 ●	O 73 ●	F 72 ●	Ne 71 ●
	3	Na 186 ●	Mg 160 ●		Al 143 ●	Si 118 ●	P 110 ●	S 103 ●	Cl 100 ●	Ar 98 ●
	4	K 227 ●	Ca 197 ●		Ga 135 ●	Ge 122 ●	As 120 ●	Se 119 ●	Br 114 ●	Kr 112 ●
	5	Rb 248 ●	Sr 215 ●		In 167 ●	Sn 140 ●	Sb 140 ●	Te 142 ●	I 133 ●	Xe 131 ●
	6	Cs 265 ●	Ba 222 ●		Tl 170 ●	Pb 146 ●	Bi 150 ●	Po 168 ●	At (140) ●	Rn (140) ●
	7	Fr (270) ●	Ra (220) ●							

Figure 3.3: Atomic radii of the main group elements (in picometer)

Consider electronic configuration of Li ($1s^2 2s^1$) and Na ($1s^2, 2s^2, 2p^6, 3s^1$). A new electronic shell has been added that increases atomic size.

Example 3.6: Identifying the element that has greater atomic radius

Choose the element whose atom you expect to have larger atomic radius in each of the following pairs.

- (a) Mg, Al (b) C, Si

Problem Solving Strategy:

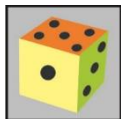
Remember that the larger atom in any:

- Period lies further to the left in the periodic table.
- Group lies closer to the bottom in the periodic table.
- Check the periodic table and choose the element.



Solution:

- (a) The larger atom is Mg
(b) The larger atom is Si



Self-Assessment Exercise 3.6

Using the periodic table but without looking at the figure 3.3, choose the element whose atom you expect to have smaller atomic radius in each of the following pairs.

- (a) O or S (b) O or F

3.2.3 Ionization Energy

	IA							VIIA	VIIIA
1	H 1312								He 2372
2	Li 520	Be 899	B 801	C 1086	N 1402	O 1314	F 1681	Ne 2081	
3	Na 496	Mg 738	Al 578	Si 786	P 1012	S 1000	Cl 1251	Ar 1521	
4	K 419	Ca 590	Ga 579	Ge 762	As 947	Se 941	Br 1140	Kr 1351	
5	Rb 403	Sr 549	In 558	Sn 709	Sb 834	Te 869	I 1008	Xe 1170	
6	Cs 376	Ba 503	Tl 589	Pb 716	Bi 703	Po 812	At 926	Rn 1037	

Figure 3.4 Ionization energies of the main group elements

You have learned in section 1.3.1 how cations are formed. Ionization energy is an important property of atoms that explains cation formation. **“Ionization energy is defined as the minimum amount of energy required to remove the outermost electron from an isolated gaseous atom”.**



Ionization energy is a measure of the extent to which the nucleus attracts the outermost electron. A high value of ionization energy means stronger attraction between the nucleus and the outermost electron. Whereas a low

ionization energy indicates a weaker force of attraction between the nucleus and the outermost electron. Figure 3.4 shows the ionization energies of the main group elements. Values are given in units of kJ/mole^{-1} or kJ/mole .

Trends in the values of ionization energies.

The ionization energy value decreases from top to bottom in a group. This is because the shielding effect in atoms increases as you descend. Greater shielding effects results in a weaker attraction of the nucleus for the valence electrons. So, they are easier to remove. This leads to decrease in ionization energy from top to bottom in a group.

Which atom has greater shielding effect, Li or Na?

As you move from left to right in a period, the shielding effect remains constant. But progressively nuclear charge increases. A stronger force of attraction between nucleus and the



valence electron increases. This leads to increase in ionization energy from left to right in a period.

Which atom has higher ionization energy, Li or Be?

Example 3.7: Identifying the element that has smaller ionization energy

Choose the element whose atom you expect to have smaller ionization energy in each of the following pairs.

- (a) B, C (b) N, P

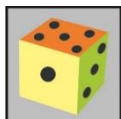
Problem Solving Strategy

Remember that ionization energy:

- (a) Increases across a period. The element that has smaller ionization energy will be further to the left in the periodic table.
- (b) Decreases from top to bottom in a group. The element that has smaller ionization energy will correspond to the element closer to the bottom.
- (c) Check the periodic table to choose the element.

Solution:

- (a) The atom with the smaller ionization energy is B
- (b) The atom with the smaller ionization energy is P.

**Self-Assessment Exercise 3.7**

Which atom has the smaller ionization energy?

- (a) B or N (b) Be or Mg (c) C or Si

3.2.4 Electron Affinity

Electron affinity explains the anion formation. **Electron affinity is defined as the amount of energy released when an electron adds up in the valence shell of an isolated atom to form a uninegative gaseous ion.**

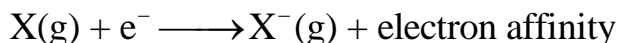


Figure 3.5 shows electron affinities of main group elements.

As you move from left to right across a period, the electron affinity generally increases. This is due to increase in nuclear charge and decrease in atomic radius, which binds the extra electron more tightly to the nucleus. But shielding effect remains constant in each period. Therefore, alkali metals have lowest and halogens have the highest electron affinities in each period.



The electron affinity decreases from top to bottom in a group. This is due to increase in shielding effect. Due to increase in shielding effect added electron binds less tightly to the nucleus. As a result less energy is released.

H -73								He 0
Li -60	Be 0		B -27	C -122	N +7	O -141	F -328	Ne 0
Na -53	Mg 0		Al -44	Si -134	P -71.7	S -200	Cl -349	Ar 0
K -48	Ca 0		Ga -29	Ge -120	As -77	Se -195	Br -325	Kr 0
Rb -47	Sr 0		In -29	Sn -121	Sb -101	Te -190	I -295	Xe 0
Cs -45	Ba 0		Tl -30	Pb -110	Bi -110	Po -180	At -270	Rn 0

Figure 3.5 electron affinities of main group elements

There are several exceptions to the general trend of electron affinity values. You will learn reasons for it in grade XI.

3.2.5 Electronegativity

Electronegativity is the ability of an atom to attract the electrons towards itself in a chemical bond. Figure 3.6 shows a scale of electronegativities of the elements devised by Linus Pauling. The American chemist Linus Pauling devised a method for calculating relative electronegativities of elements.

H 2.1							He
Li 1.0	Be 1.5	B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne 2.1
Na 0.9	Mg 1.2	Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar 3.0
K 0.5	Ca 1.0	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 2.1
Rb 0.8	Sr 1.0	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6
Cs 0.7	Ba 0.9	Tl 1.8	Pb 1.9	Bi 1.9	Po 2.0	At 2.2	Rn
Fr 0.7	Ra 0.9						

Figure 3.6 the electronegativities of elements.

**Activity 3.3****Determining the general trends in the electronegativities****You will need:**

- Figure 3.6

Carry out the following:

1. Move across the second period from left to right and note down the variation in electronegativity values.
2. Move across the 3rd period from left to right and note down the variation in electronegativity values.
3. Make generalization about the variation in electronegativities across a period and write reason.
4. Move from top to bottom in Groups IA and IIA and note down the variation in electronegativities value.
5. Move from top to bottom in Groups VIA and VIIA and note down the variation in electronegativities value.
6. Make generalization about the trend in electronegativity values in a group. Give reason.

**Key Points**

- When elements are arranged in the order of their increasing atomic number, their properties are repeated in a periodic manner.
- A horizontal row of elements in the periodic table is called a period.
- A column of elements in the periodic table is called a group or a family.
- Group IA and IIA elements are called s-block elements, since s sub-shell fills in these elements.
- Elements in group IIIA to VIIIA are called p-block elements, because filling of valence p sub-shell occurs in these elements.
- The length of a period in the periodic table depends on the type of sub-shell that fills.
- The decrease in force of attraction between nucleus and the valence electron by the electrons present in the inner sub-shells is called shielding effect.
- The size of atom is the average distance between the nucleus of an atom and the outer electronic shell.
- The atomic radii decrease from left to right in a period. Whereas these increase from top to bottom in a group.
- Ionization energy is the minimum amount of energy required to remove the outermost electron from an isolated gaseous atom.



- Electron affinity is the amount of energy released when an electron adds up in the valence shell of an isolated atom to form a uninegative gaseous ion.

REFERENCES FOR ADDITIONAL INFORMATION

- B.Earl and LDR Wilford, Introduction to Advanced Chemistry.
- Iain Brand and Richard Grime, Chemistry (11-14).
- Lawarie Ryan, Chemistry for you.



Review Questions

1. Encircle the correct answer:

- Number of periods in the periodic table are:
(a) 8 (b) 7 (c) 16 (d) 5
- Which of the following groups contain alkaline earth metals?
(a) 1A (b) IIA (c) VIIA (d) VIIIA
- Which of the following elements belongs to VIIIA?
(a) Na (b) Mg (c) Br (d) Xe
- Main group elements are arranged in _____ groups.
(a) 6 (b) 7 (c) 8 (d) 10
- Period number of ${}_{13}^{27}\text{Al}$ is:
(a) 1 (b) 2 (c) 3 (d) 4
- Valence shell electronic configuration of an element M (atomic no. 14) is:
(a) $2s^2 2p^1$ (b) $2s^2 2p^2$ (c) $2s^2 2p^3$ (d) $3s^2 3p^2$
- Which of the following elements you expect to have greater shielding effect?
(a) Li (b) Na (c) K (d) Rb
- As you move from right to left across a period, which of the following does not increase:
(a) electron affinity (b) ionization energy
(c) nuclear charge (d) shielding effect
- All the elements of Group IIA are less reactive than alkali metals. This is because these elements have:
(a) high ionization energies (b) relatively greater atomic sizes
(c) similar electronic configuration (d) decreased nuclear charge

2. Give short answers

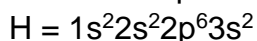
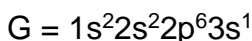
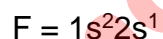
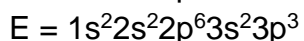
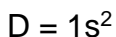
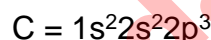
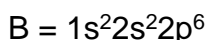
- Write the valence shell electronic configuration of an element present in the 3rd period and Group IIIA.
- Write two ways in which isotopes of an element differ.
- Which atom has higher shielding effect, Li or Na?
- Explain why, Na has higher ionization energy than K?
- Alkali metals belong to S-block in the periodic table, why?



3. Arrange the elements in each of the following groups in order of increasing ionization energy:
(a) Li, Na, K (b) Cl, Br, I
4. Arrange the elements in each of the following in order of decreasing shielding effect.
(a) Li, Na, K (b) Cl, Br, I (c) Cl, Br
5. Specify which of the following elements you would expect to have the greatest electron affinity.

S, P, Cl

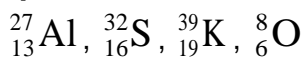
6. Electronic configuration of some elements are given below, group the elements in pairs that would represent similar chemical properties.



7. Arrange the elements in groups and periods in Q. No. 6.

IA								VIIIA
	IIA							
			IIIA	IVA	VA	VIA	VIIA	

8. For normal elements, the number of valence electrons of an element is equal to the group number. Find the group number of the following elements.



9. Write the valence shell electronic configuration for the following groups:
- Alkali metals
 - Alkaline earth metals
 - Halogens
 - Noble gases
10. Write electron dot symbols for an atom of the following elements
(a) Be (b) K (c) N (d) I
11. Write the valence shell electronic configuration of the atoms of the following elements.
- An element present in period 3 of Group VA
 - An element present in period 2 of Group VIA



12. Copy and complete the following table:

Atomic number	Mass number	No. of protons	No. of neutrons	No. of electrons
11			12	
		14	15	
	47		25	
	27			13

13. Imagine you are standing on the top of Neon-20 nucleus. How many kinds of sub-atomic particles you would see looking down into the nucleus and those you would see looking out from the nucleus.
14. Chlorine is a reactive element used to disinfect swimming pools. It is made up of two isotopes Cl-35 and Cl-37. Because Cl-35 is more than Cl-37, the atomic mass of chlorine is 35.5amu. is closer to 35 than 37. Write electronic configuration of each isotope of chlorine. Also write symbol for these isotopes (atomic number for chlorine is 17).
15. In which block, group and period in the periodic table where would you place each of the following elements with the following electronic configurations?
 (a) $1s^2 2s^1$ (b) $1s^2 2s^2 2p^5$ (c) $1s^2 2s^2 2p^6 3s^2$ (d) $1s^2$



Think-Tank

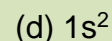
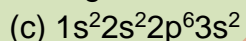
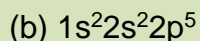
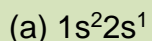
- What types of elements have the highest ionization energies and what types of elements have the lowest ionization energies. Argue.
- Two atoms have electronic configuration $1s^2 2s^2 2p^6$ and $1s^2 2s^2 2p^6 3s^1$. The ionization energy of one is 2080kJ/mole and that of the other is 496kJ/mole. Match each ionization energy with one of the given electronic configuration. Give reason for your choice.
- Use the second member of each group from Group IA, IIA and VIIA to judge that the number of valence electron in an atom of the element is the same as its group number.
- Letter A, B, C, D, E, F indicates elements in the following figure:

					C			
A				B				
	D				E			
							F	



- a. Which elements are in the same periods?
- b. Write valence shell electronic configuration of element D.
- c. Which elements are metals?
- d. Which element can lose two electrons?
- e. In which group E is present?
- f. Which of the element is halogen?
- g. Which element will form dipositive cation?
- h. Write electronic configuration of element E
- i. Which two elements can form ionic bond?
- j. Can element C form C_2 molecule? Interpret.
- k. Which element can form covalent bonds?
- l. Is element F a metal or non-metal?

5. Electronic configurations of four elements are given below:



Which of these elements is

- i) An alkali metal
- ii) An alkaline earth metal
- iii) A noble gas
- iv) A halogen

6. Argue in what region of the periodic table you will find elements with relatively

- a) high ionization energies
- b) low ionization energies



4

STRUCTURE OF MOLECULES



This is a 20 days lesson

After completing this lesson, you will be able to:

- Find the number of valence electrons in an atom using the Periodic Table
- Describe the importance of noble gas electronic configurations.
- Describe the formation of cations from an atom of a metallic element. Describe the formation of anions from an atom of a non-metallic element.
- Describe the ways in which bonds may be formed.
- Describe the formation of a covalent bond between two nonmetallic elements.
- Describe with examples single, double and triple covalent bonds.
- Draw electron cross and dot structures for simple covalent molecules containing single, double and triple covalent bonds.
- Explain how element attain stability.
- Recognize a compound as having ionic bonds. Identify characteristic of ionic compounds.
- State the octet and duplet rules
- State the importance of the noble gas electronic configurations in the formation of ion.



Pre- Reading

All the matter in this world is composed of almost entirely compounds and their mixtures. Human, animal and plant bodies, rocks, soil, petroleum, coal etc. are all complex mixtures of compounds. In compounds different kinds of atom are bounded together. Few elements also consist of unbounded atoms. For instance helium, neon, argon, xenon and krypton present in the atmosphere consist of unbounded atoms. The manner in which various atoms are bonded together has a profound effect on the properties of substances.

Some substances are hard and tough, others are soft and

flexible why? Resins are widely used to paint dams, bridges, buildings and automobiles. What makes them sticky? How do adhesives such as glue bind two surfaces together? What is the nature of such linkages? The answer lies in the nature of bonding and structure of their molecules. Therefore, to understand the behaviour of various substances, you must understand the nature of chemical bonding and structure of molecules.



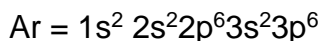
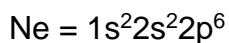
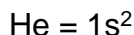
Reading

4.1 WHY DO ATOMS REACT?

In chapter 3, you have learned the arrangement of elements on the periodic table. You noticed that each period on the periodic table starts with alkali metal (except period I that starts



with hydrogen) and ends at a noble gas. The noble gases have ns^2np^6 electronic configuration in the outer most shell. These elements are sometimes called the inert gases. This is because they do not participate in chemical reactions. Electronic configurations of first three noble gases are shown below:



Note that these elements have completely filled outer most s and p sub-shells. Helium contains two electrons and remaining noble gases contain 8 electrons in the valence shell. Because of these configuration noble gases are stable and not active. In 1916 a chemist G.N. Lewis used this fact to explain why atoms undergo chemical reactions. He called his explanations as Octet Rule. An octet is a set of eight. In forming compounds, atoms tend to gain electronic configuration of a noble gas. Remember that each noble gas (except He) has eight electrons configuration in the valence shell. Thus the octet rule takes its name from this fact about noble gases.

The tendency of atoms to acquire eight electron configuration in their valence shell, when bonding, is called octet rule.

Helium has two electrons in its valence shell and is also chemically inert. Some elements that are close to He on the periodic table tend to achieve two electron configuration in their valence shell. For example hydrogen, lithium and beryllium etc tend to achieve two electron configuration in the valence shell.

The tendency of some atoms to acquire two electron configuration in their valence shell, when bonding, is called duplet rule.

Example 4.1: Obtaining the number of valence electrons in an atom using the periodic table.

Find the number of valence electrons in the following atoms using the periodic table.

- (a) Carbon (b) Magnesium (c) Phosphorus

Problem Solving Strategy:

Remember that the group number of main group elements indicates the number of valence electrons in an atom. Check the group number of the elements in the periodic table and find the number of valence electrons.

Solution:

- (a) Carbon belongs to Group IVA, so it contains four electrons in the valence shell.
- (b) Magnesium belongs to Group IIA, so it contains two electrons in the valence shell.
- (c) Phosphorus is present in Group VA, so it has five electrons in the valence shell.

**Self-Assessment Exercise 4.1**

Find the number of electrons in valence shell of the following atoms using the periodic table. (a) Silicon (b) Sulphur (c) Bromine (d) Argon (e) Potassium (f) Nitrogen

**Reading**

4.2. CHEMICAL BONDS

Atoms combine to form various types of substances. But what holds them together? Fundamentally, some forces of attraction hold atoms together in substances. These forces are called chemical bonds. Basically the forces of attraction that lead to chemical bonding between atoms are electrical in nature. Electronic structure of an atom helps us to understand how atoms are held together to form substances. Atoms other than the noble gases have a tendency to react with other elements. These elements are reactive because they tend to gain stability by losing or gaining electrons. When atoms gain or lose electron they acquire the configuration of next noble gas element.

Atoms can also acquire the configuration of next noble gas element by sharing electrons.

4.3 TYPES OF BONDS

Depending on the tendency of an atom to lose or gain or share electrons, there are two types of bonds:

1. Ionic bonds
2. Covalent bonds

4.3.1 Ionic Bonds

Ionic bonds are formed between two atoms, when one atom loses electron to form cation and the other atom gains this electron to form anion.

Example 4.2: Describing the formation of cations.

Describe the formation of Na^+ and Mg^{+2} cations.

Problem Solving Strategy:

1. Sodium belongs to Group IA on the periodic table. It has only one electron in the valence shell. Sodium atom loses its valence electron and is left with an octet. Represent this by drawing the complete electronic configuration or using an electron dot structure.
2. Magnesium belongs to Group IIA in the periodic table. It has two valence electrons. Magnesium atom loses these electrons to achieve noble gas configuration. Represent

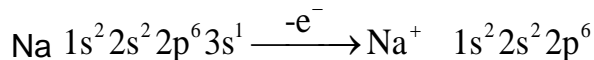


this by drawing the complete electronic configuration or using an electron dot structure.

This number also corresponds to the Group number in the periodic table.

Solution:

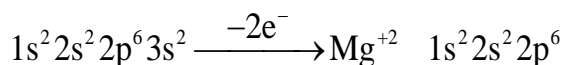
(a) Formation of Na^+ ion



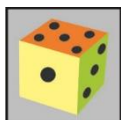
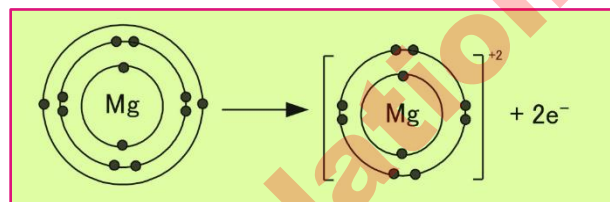
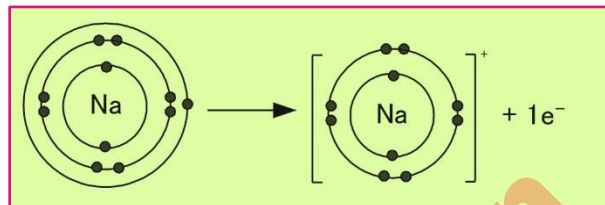
You can also represent this by following electron dot structure,

(b) Formation of Mg^{+2} ion

Mg



You can also represent this by electron dot structure,



Self-Assessment Exercise 4.2

- Describe the formation of cations for the following metal atoms:
 - Li(atomic no 3)
 - Al(atomic no. 13)
- Represent the formation of cations for the following metal atoms using electron dot structures.
 - K
 - Ca

Example 4.3: Describing the formation of anions.

Describe the formation of anions for the following non-metal atoms:

- Oxygen(atomic no.8)
- Fluorine (atomic no. 9)

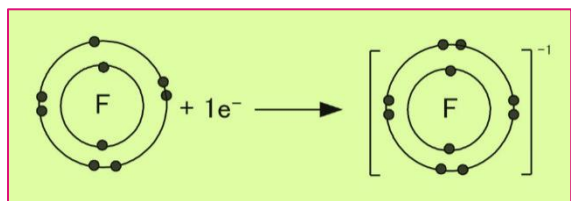
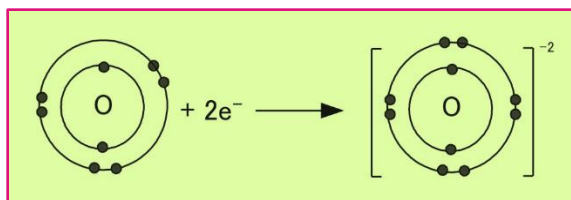
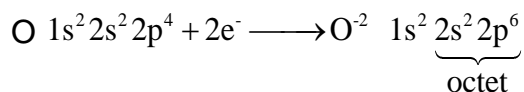
Problem Solving Strategy:

- Write electronic configuration or dot structure.
- Find the number of electrons needed to acquire eight electron configuration.
- Represent addition of electrons.

Solution:

(a) Formation of anion by oxygen atom.

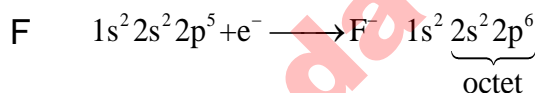
Oxygen belongs to Group VIA on the periodic table. So it has six electrons in its valence shell. It needs two electrons to achieve noble gas configuration.



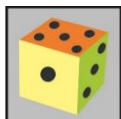
You can also represent this by electron dot structure,

(b) Formation of anion by fluorine atom

Fluorine belongs to Group VIIA on the periodic table. So it has seven electrons in the valence shell. A fluorine atom therefore, requires only one electron to complete octet.



You can also represent this by electron dot structure,



Self-Assessment Exercise 4.3

- Describe the formation of anions by the following non-metals.
 - Sulphur (atomic No. 16)
 - Chlorine (atomic No. 17)
- Represent the formation of anions by the following non-metals using electron dot structures.
 - N
 - P
 - Br
 - H

Anions and cations have opposite charges. They attract one another by electrostatic forces. **“The forces of attraction that bind oppositely charged ions are called ionic bonds”**. Compounds that consist of ions joined by electrostatic forces are called ionic compounds. The total positive charge of the cations must be equal to the total negative charge of the anions. This is because ionic compounds as a whole are electrically neutral.

Example 4.4: Representing ionic bond formation.

For each of the following pairs of atoms, use electron dot & electron cross structures to write the equation for the formation of ionic compound.

- Na and Cl
- Mg and F

Problem Solving Strategy:

- The metal atoms form cations and non-metal atoms form anions.
- The number of electrons lost by metal atoms of group IA, IIA and IIIA equals the group number.

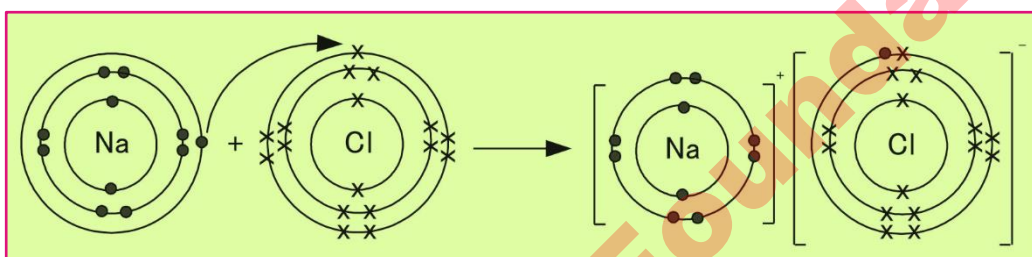


- To write the final form of the equation, you need to know the simplest ratio of cations to anions that you require for the neutral compound.
- Write equation using electron dot & electron cross structures.

Solution:

(a) Na is metal and Cl is non-metal.

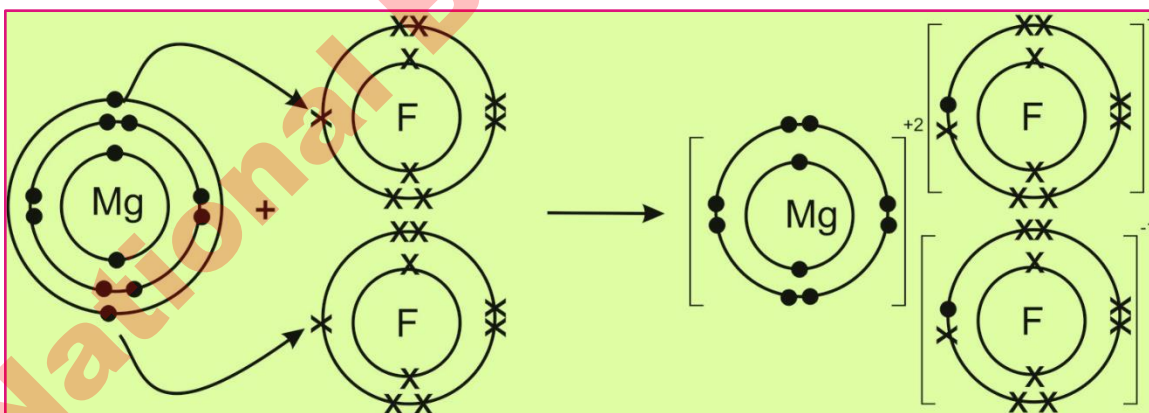
Metal atom tends to lose electrons and non – metal atoms tends to gain electrons to acquire electronic configuration of nearest noble gas. Since Na atom has one electron in the outer most shell. It losses one electron to form Na^+ ion. Since Cl atom has seven electrons in outermost shell, it needs one electron to complete octet. So it gains one electron to form Cl^- ion. For every Na^+ ion, you need one Cl^- ion.



(b) Mg is metal and F is non-metal.

Mg atom has two electrons in the outermost shell. It losses two electrons to form Mg^{+2} ion. Since F atom has seven electrons in the outermost shell, so it gains one electron to form F^- ion.

For every Mg^{+2} ion you need two F^- ions.

**Self-Assessment Exercise 4.4**

For each of the following pairs of atoms, use electron dot and electron cross structures to write the equation for the formation of ionic compound.

- (a) Mg and O (b) Al and Cl

**Example 4.5: Recognizing a compound as having ionic bonds.**

Recognize the following compounds as having ionic bonds.

(a) MgO (b) NaF

Problem Solving Strategy:

1. The metal atom loses electrons to form cations and non-metal atom gains electrons to form anions.
2. The number of electrons lost by metal atoms of group IA, IIA and IIIA equals the group number. The number of electrons gained by the non-metal atoms is equal to 8 minus group number.
3. Find the simplest ratio of cations to anions, to identify the compound.

Solution:

(a) MgO

Mg is metal and O is non-metal. Mg atom has two electrons in outermost shell. So it loses two electrons to form Mg^{+2} ion. Since O atom has six electrons in outermost shell, so it gains two electrons to form O^{-2} ion. In this way both the atoms acquire nearest noble gas configuration. For every Mg^{+2} ion you need one O^{-2} ion. Chemical formula of resulting compound is MgO. Therefore MgO is an ionic compound.

(b) Na is metal and F is non-metal. Na atom has one electron in outmost shell. So it loses one electron to form Na^{+} ion. Since F atom has seven electrons in outermost shell, so it gains one electron to form F^{-} ion. Na atom by losing one electron and F atom by gaining one electron acquire nearest noble gas electronic configuration. You need one F^{-} ion for each Na^{+} ion. Therefore, NaF is an ionic compound.

**Self-Assessment Exercise 4.5**

Recognize the following compounds as having ionic bonds:

(a) KCl (b) AlCl_3 (c) MgF_2

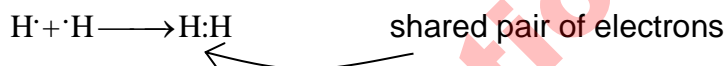
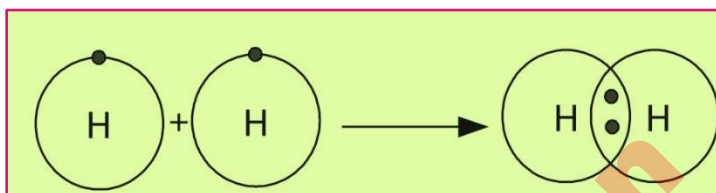
**Reading****4.3.2 Covalent Bonds**

In the preceding section you have learned the formation of ionic bonds between two atoms. Ionic compounds such as NaCl, are crystalline solids with high melting points. However, some compounds have very different properties. HCl is a gas at room temperature. Water (H_2O) is a liquid. Such compounds are not ionic. These compounds are made up of non-metal atoms. Non-metals have high ionization energies, therefore, they do not lose electrons. Non-metal



atoms tend to share electrons among themselves or with other non-metal atoms to form a chemical bond called covalent bond. **A Covalent bond is formed by mutual sharing of electrons between two atoms.**

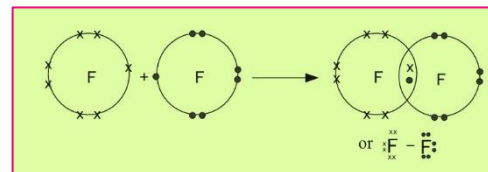
Consider the formation of covalent bond in hydrogen molecule. A hydrogen atom has a single valence electron. Two hydrogen atoms share their valence electrons to form a diatomic molecule.



In the formation of this molecule, each hydrogen atom achieves the electron configuration of the noble gas, helium which has two valence electrons. An electron pair in the region between the two atoms is attracted to both hydrogen nuclei. This means it is a more stable situation than that exists in separate atoms. Because of this stability two atoms form a covalent bond.

We can represent the formation of a covalent bond between two atoms using electron-dot and electron-cross symbols for the atoms and the resulting molecule. As already discussed that valence electrons are represented by dots. Just to understand sharing, we represent valence electrons in one atom by dots and in the other atom by crosses. However, remember that all the electrons are identical and cannot be differentiated. A shared pair of electrons is also represented by a dash (-) in a molecule.

Consider the formation of a bond between two fluorine atoms. Fluorine belongs to Group VIIA, so it has seven electrons in the valence shell. It needs one more electron to attain the electron configuration of a noble gas. Thus two F-atoms share an electron pair and achieve electron configuration of Ne. For sharing each F-atom contributes one electron to complete the octet.

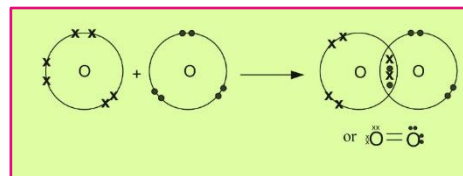


Pairs of valence electrons which are not shared between atoms are called unshared pairs or lone pairs.

Covalent bond that is formed by the sharing of one electron pair is called single covalent bond. So H_2 and F_2 molecules contain a single covalent bond.

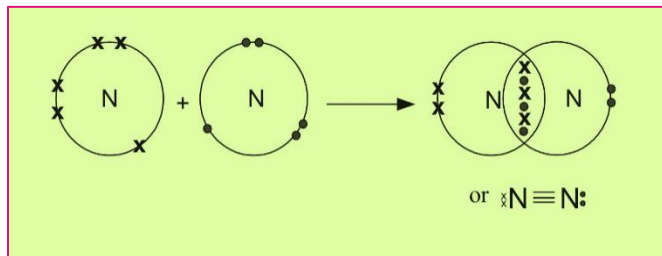
Can you explain the formation of covalent bond between H-atom and a F-atom?

Sometimes atoms may share two or three electron pairs to complete octet. **Double covalent bonds are the bonds that are formed by sharing of two electron pairs.** **Triple covalent bonds are the bonds that involve three shared pairs of electrons.**



Teacher's Point

A teacher may show bonds to students by balls and springs.



Consider the formation of O_2 molecule. Oxygen is in Group VI A, so it has 6 electrons in the valence shell. It needs two electrons to complete its octet. So for sharing each O-atom contributes two electrons.

Can you explain the formation of N_2 molecule?

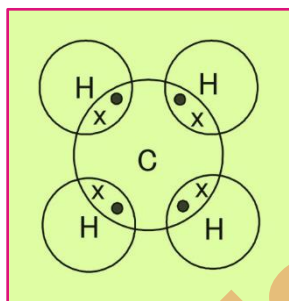
Example 4.6: Drawing electron cross and dot structures for simple covalent molecules containing single covalent bonds

Draw electron cross and dot structures for (a) CH_4 that is a major component of natural gas (b) H_2O that covers about 80% of the earth crust.

Problem Solving Strategy:

1. Decide from the chemical formula which atom is the central atom. An atom that contributes more electrons for sharing is the central atom. Show its valence electrons by dots. Note the number of electrons it needs to complete octet. If the number of electrons needed equals the other atoms, each atom will form a single covalent bond.
2. Arrange other atoms around the central atom. Connect the central atom by single bonds. Use cross to represent electrons of the other atoms.
3. Check whether the arrangement of electron satisfies the octet rule.

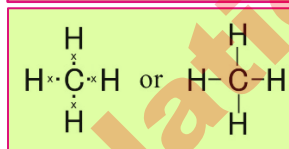
Solution:



(a) CH_4

(i) C has four electrons in the valence shell and needs four electrons to complete its octet. H has only one valence electron and needs one electron to complete duplet. So C can form four single bonds with four H-atoms. C is the central element.

(ii) Connect the atoms with a dot and a cross

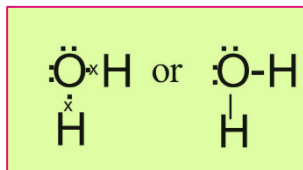
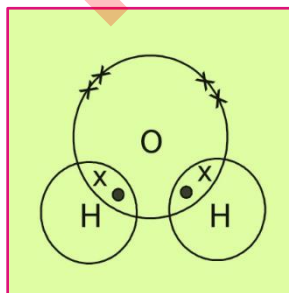


H_2O

(i) O has six valence electrons $\text{:}\ddot{\text{O}}\text{:}$ and each hydrogen atom has one valence electron H^\cdot . So O-atom needs two electrons to complete octet. Each H needs one electron to complete duplet.

(ii) O is central atom and will form two single bonds with H-atoms.

(iii) Arrange H-atoms around O and connect them by a pair of electrons (one dot and one cross)



**Self-Assessment Exercise 4.6**

Draw electron cross and dot structures for the following molecules:

- NH_3 that is used to manufacture urea.
- CCl_4 , a dry cleansing agent.
- SiCl_4 , used to make smoke screens.
- H_2S , a poisonous gas.

Example 4.7: Drawing electron cross and dot structures for molecules containing multiple bonds

Draw electron cross and dot structures for the following molecules:

- CO_2 , a component of air and is responsible for green house effect.
- HCN , used as insecticide.

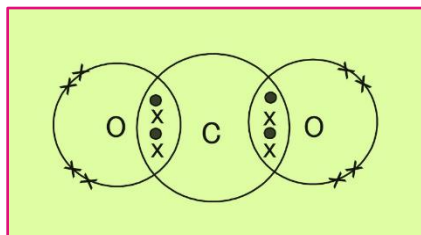
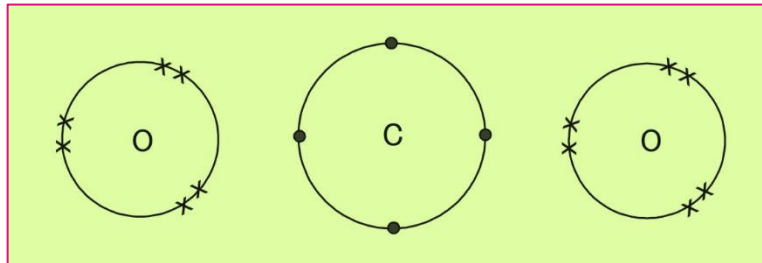
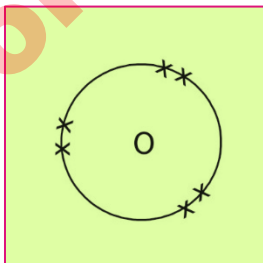
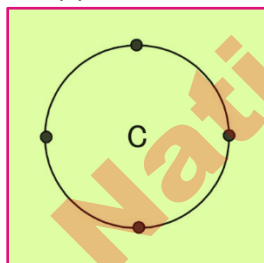
Problem Solving Strategy:

- Decide from the formula which atom is to be in the center. Show its valence electrons by dots. Note the number of electrons it needs to complete octet.
- Show valence electron of the other atoms by cross and find the number of electrons each of the atoms needs to complete octet or duplet.
- Connect central atom with the other atoms by electron pair or pairs to satisfy the octet rule.

Solution:

(a) CO_2

- C has four electrons in the valence shell. It needs four electrons to complete octet.
- Each oxygen atom has six valence electrons and needs two electrons to have an octet.



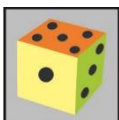
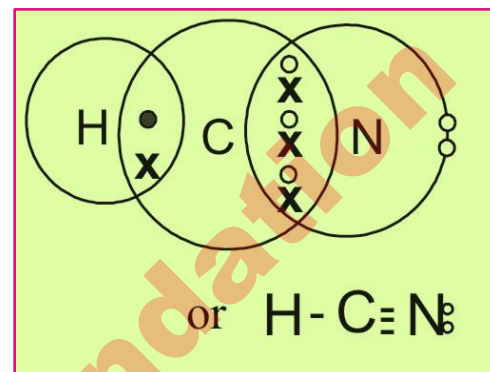
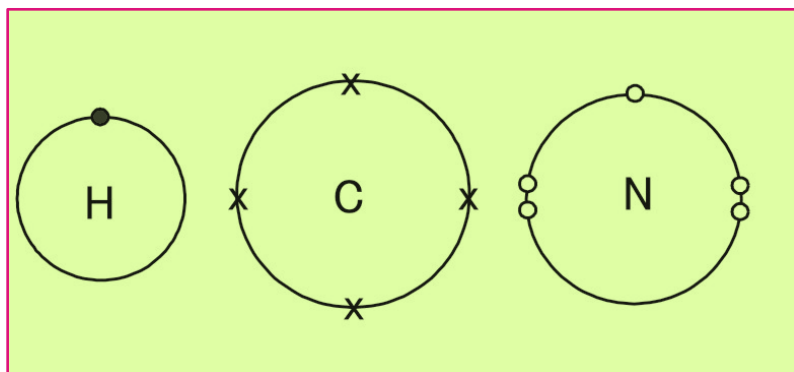
(iii) C is central atom, arrange O-atoms around it.

(iv) Since C needs four electrons and there are only two oxygen atoms. So it will share its two electrons with each oxygen atom.





- (b) HCN
- (i) H has one, C has four and N has five electrons.
- (ii) C needs four and N needs three electrons. So C shares one electron with H to form a single bond and three electrons with N to form a triple bond. This will satisfy octet rule.



Self-Assessment Exercise 4.7

Draw electron cross and electron dot structures for the following molecules:

- (a) CS_2 an organic solvent that dissolves sulphur, phosphorus etc
- (b) N_2 a component of air.

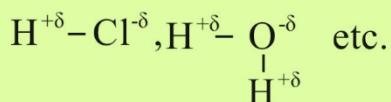


Reading

4.4 INTERMOLECULAR FORCES

A covalent bond can occur between two similar atoms such as in H_2 , N_2 , O_2 , Cl_2 etc. It can also occur between two unlike atoms, such as in HCl , H_2O , NH_3 , HCN , CO_2 etc.

When two identical atoms share electron pairs, both the atoms exert same force on the shared electron pairs. Such a covalent bond is called non-polar covalent bond. For example, bond in $\text{H}-\text{H}$, $\text{O}=\text{O}$, $\text{N}\equiv\text{N}$ etc are non-polar covalent bonds. On the other hand, when two different atoms share electron pair, both the atoms exert different forces on the shared electron pair. More electronegative atom pulls shared electrons pairs with greater force towards itself than the other. So more electronegative atom partially draws electron density towards itself. This makes it partially negatively charged and other atom partially positively charged. Such a covalent



bond is called polar covalent bond. The forces of attraction thus created between the molecules are called intermolecular forces. For example,



These intermolecular forces are weaker than an ionic or a covalent bond. There are several types of intermolecular forces. We will discuss two of these. Dipole-dipole interactions occur between polar molecules. Figure 4.1 shows these interactions

You know that paints and dyes are used to protect solid surfaces from the atmospheric effects. They also give visual appeal. Resins are used to coat materials that give toughness, flexibility, adhesion and chemical resistance. For example dams, bridges, floors, trains, buses, cars etc are painted with resins. The synthetic resins are used where water resistance is required. Chemically, resins are either adhesive or they form bond linkages with the material being bonded together. What is the nature of these linkages?

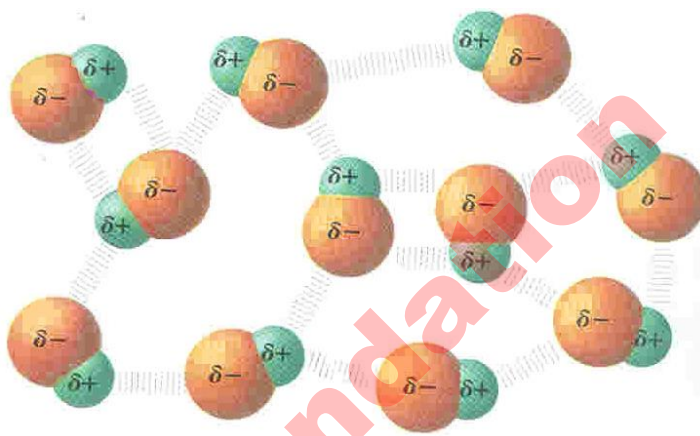


Fig 4.1: Dipole-Dipole interactions

Notice that slightly negative end of polar molecule is weakly attracted to the slightly positive end of another molecule. Such attracting forces are called dipole-dipole interactions.

Molecules in which hydrogen is covalently bonded to a very electronegative atom such as oxygen, nitrogen or fluorine is also weakly bonded to a lone pair of electron of another electronegative atom. This other atom may occur in the same molecule or in a nearby molecule. This intermolecular interaction is called hydrogen bonding. Oxygen, nitrogen or fluorine makes hydrogen very electron-deficient. Thus interaction of such a highly electron deficient hydrogen and lone pair on a nearby electronegative atom compensates for the deficiency. Figure 4.2 shows hydrogen bonding in water molecules.

The interaction of a highly electron deficient hydrogen and lone pair on a nearby highly electronegative atom such as N, O or F is called hydrogen bond. This phenomenon is called hydrogen bonding.

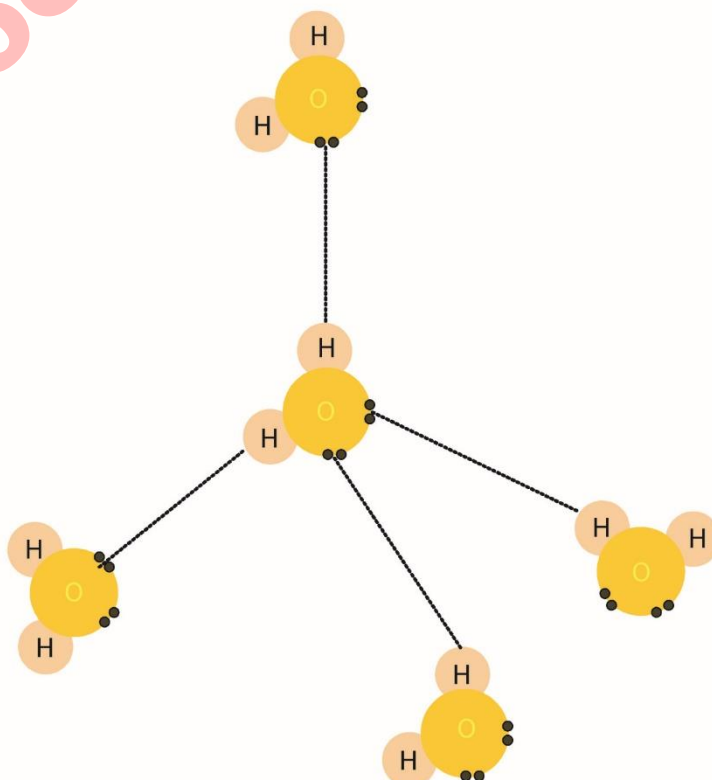


Fig 4.2: Hydrogen bonding in water



Society, Technology and Science

Epoxy adhesives have excellent chemical resistance, good adhesion properties, good heat resistance and they form strong and tough coating. Therefore, propellers and parts of aircraft, boats, cars, trucks etc are held together by epoxy adhesives. Epoxy adhesives contain partially positively charged H-atoms and oxygen atoms containing lone pairs in their molecules. Epoxy adhesives are, therefore, sticky and can make H-bonds with other substances. Modern aircraft, boats and automobiles such as cars, trucks etc and even in space craft epoxy adhesives are used for assembling, saving money and reducing weight. This means glues and adhesives have become an essential item in our daily life.

These intermolecular forces are extremely important in determining properties of water, biological molecules, such as proteins, DNA etc and synthetic materials such as glue, paints, resins etc. The adhesive action of paints and dyes is developed due to hydrogen bonding. Synthetic resins bind two surfaces together by hydrogen bonding or dipole-dipole interactions.

4.5 NATURE OF BONDING AND PROPERTIES

Compounds that consist of ions joined by electrostatic forces are called ionic compounds. At room temperature most of the ionic compounds are crystalline solids. Figure 4.3 shows arrangement of ions in NaCl and CsCl crystals.

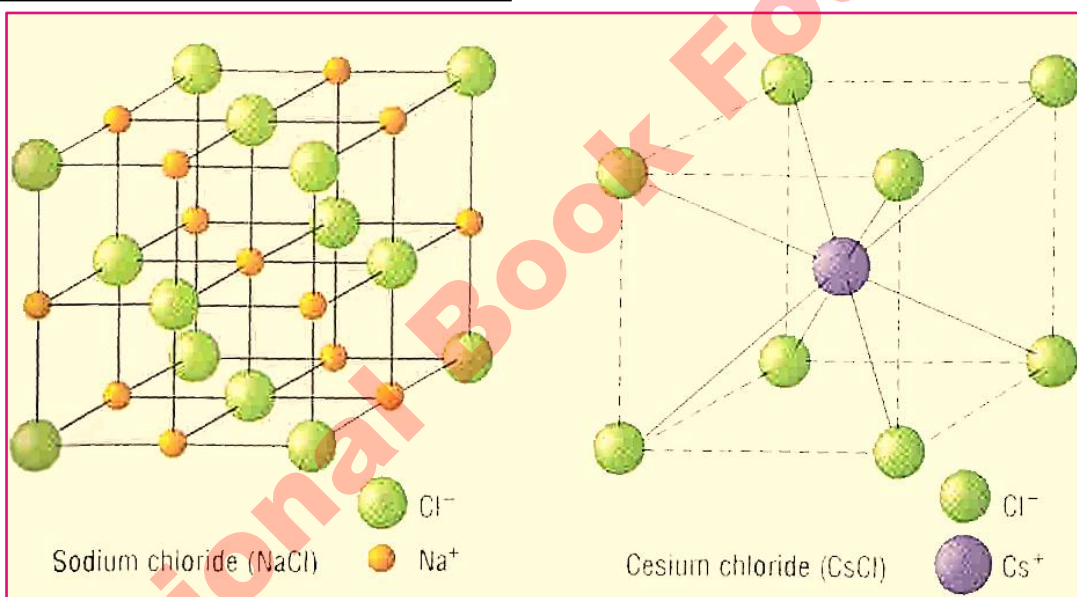


Fig 4.3: Arrangement of ions in NaCl and CsCl crystals

Note that both NaCl and CsCl form colorless cubic crystals. Each Na^+ ion is surrounded by six Cl^- ions and each Cl^- ion is surrounded by six Na^+ ions. Internal structure of CsCl is different from NaCl. In CsCl each Cs^+ ion is surrounded by eight Cl^- ions and each Cl^- ion is surrounded by eight Cs^+ ions. Thus in crystals each ion is attracted strongly to each of its neighbours. The large attracting forces result in a very stable structure. So ionic compounds have high melting points. For example, melting point of NaCl is 801°C .



Teacher's Point

A teacher may ask the students to make a model of NaCl



When melted ionic compounds conduct electricity, figure 4.4 shows that NaCl melts and the Na^+ and Cl^- ions are free to move throughout the molten salt. When voltage is applied, Na^+ ions move towards negative electrode. At the same time, Cl^- ions move towards positive electrode. This movement of ions inside a cell is responsible for flow of electricity between the electrodes in the external wire.

Aqueous solutions of ionic compounds also conduct electricity. This is because when an ionic compound dissolves in water, the ions are free to move about in the aqueous solution.

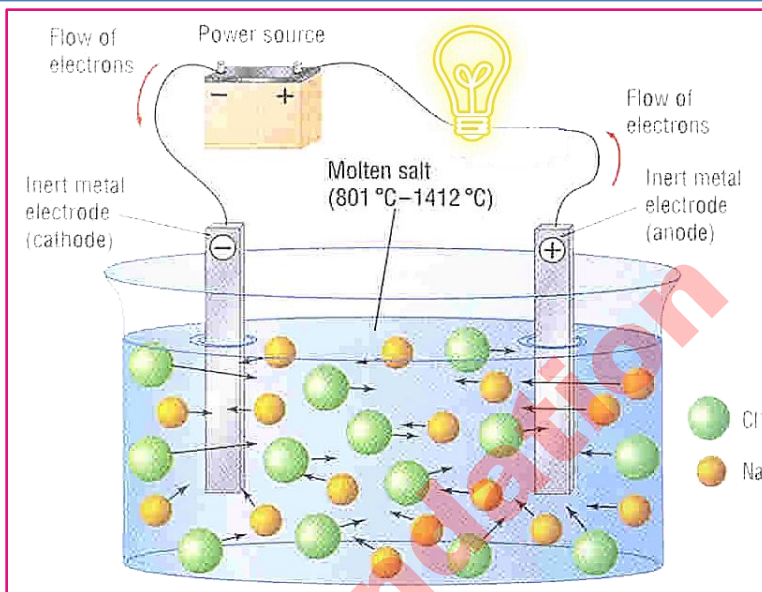


Figure 4.4: conduction of electricity through molten NaCl

Society, Technology and Science

Synthetic adhesives such as glues and epoxy resins are used in large scale industrial applications. Glues are less costly than synthetic adhesives. Glues are extensively used as an adhesive for veneer, plywood, corrugated cartons and laminated boards. Glues for glass and metal are also available. Epoxy resins are used where water resistance is required. They form strong and tough coating. They also give flexibility and chemical resistance. For these reasons, dams, bridges, thermal power stations are coated with epoxy resins. In modern air craft and automobile epoxy resin adhesives are used for assembling, saving money and reducing weight. Hence there is a need for more adhesives.



Key Points

- An octet is a set of eight. In order to gain stability atoms tend to gain electron configuration of nearest noble gas.
- The tendency of atoms to acquire eight electron configuration in their valence shell, when binding is called octet rule.
- Ionic bonds are formed between two atoms, when one atom loses electrons and other atom gains these electrons. The force of attraction that binds oppositely charged ions is called ionic bonds.
- Ionic compounds have high melting points. They conduct electricity in molten state.
- A bond that is formed by the sharing of electrons between two atoms is called a covalent bond. A covalent bond can be single, double or triple.
- The interaction of a highly electron deficient hydrogen and lone pair on a nearby electronegative atom is called hydrogen-bond.



- The adhesive action of paints and dyes is developed due to hydrogen bonding.

REFERENCES FOR ADDITIONAL INFORMATION

- Lawarie Ryan, Chemistry for you.
- Iain Brand and Richard Grime, Chemistry (11-14).
- Silberg, Chemistry.
- Raymond Chang, Essential Chemistry.



Review Questions

1. Encircle the correct answer:

- (i) Which of the following atoms will form an ion of charge -2?

<u>Atomic Number</u>	<u>Mass Number</u>	<u>Atomic Number</u>	<u>Mass Number</u>
(a) 12	24	(b) 14	28
(c) 8	8	(d) 10	20

- (ii) Which of the following atoms will not form cation or anion.

- A (Atomic No. 16)
- B (Atomic No. 17)
- C (Atomic No. 18)
- D (Atomic No. 19)

- (iii) Which of the following atoms will form cation.

<u>Atomic Number</u>	<u>Atomic Number</u>
(a) 20	(b) 18
(c) 17	(d) 15

- (vi) Which of the following atoms obey duplet rule?

(a) O_2	(b) F_2	(c) F_2	(d) N_2
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- (v) Silicon belongs to Group IVA. It has _____ electrons in the valence shell

(a) 2	(b) 3	(c) 4	(d) 6
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- (vi) Phosphorus belongs to third period of Group VA. How many electrons it needs to complete its valence shell.

(a) 2	(b) 3	(c) 4	(d) 5
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- (vii) In the formation of AlF_3 , aluminum atom loses _____ electrons.

(a) 1	(b) 2	(c) 3	(d) 4
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- (viii) Which of the following is not true about the formation of Na_2S :

- Each sodium atom loses one electron
- Sodium forms cation
- Sulphur forms anion
- Each sulphur atom gains one electron

- (ix) Identify the covalent compound

(a) NaCl	(b) MgO	(c) H_2O	(d) KF
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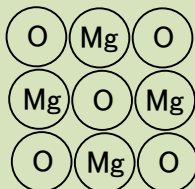


2. Give short answers
 - i. State octet and duplet rules.
 - ii. Explain formation of covalent bond between two nitrogen atoms
 - iii. How does Al form cation?
 - iv. How does O form anion?
 - v. Draw electron cross and dot structure for H_2O molecule.
3. Describe the importance of noble gas electronic configuration.
4. Explain how elements attain stability?
5. Describe the ways in which bonds may be formed.
6. Describe the formation of covalent bond between two non-metallic elements.
7. Explain with examples single, double and triple covalent bond.
8. Find the number of valence electrons in the following atoms using the periodic table:
(a) Boron (b) Neon (c) Rubidium (d) Barium (e) Arsenic
9. Represent the formation of cations for the following metal atoms using electron dot structures.
(a) Al (b) Sr (c) Ba
10. Describe the formation of anions for the following non-metal atoms:
(a) P (b) Br (c) H
11. Represent the formation of cations for the following metal atoms using electron dot structures.
(a) Mg (b) Li (c) Be
12. For each of the following pairs of atoms, use electron dot and electron cross structures to write the equation for the formation of ionic compound.
(a) K and Cl (b) Ca and S (c) Al and N
13. Recognize the following compounds as having ionic bonds.
(a) MgCl_2 (b) KBr (c) NaI
14. An atom of an element has atomic number 9 and mass number 19.
 - (a) State the number of protons and neutrons in the nucleus of this atom.
 - (b) State the number of electrons in this atom.
 - (c) Show with electron cross-dot diagrams, the formation of ions in the reaction of this atom with sodium atom.
15. Is there a need for more adhesives?
16. What is the importance of glues and adhesives in our society?



Think-Tank

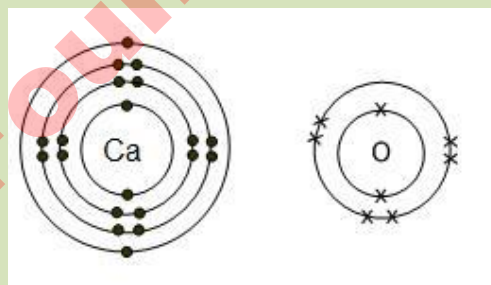
1: Magnesium oxide is a compound made up of magnesium ions and oxide ions.



- What is the charge on these ions.
- How these ions get these charges.
- Show with electron cross-dot diagrams the formation of these ions.

2: The diagrams below show the electronic structures of an atom of calcium and an atom of oxygen.

Draw structures of the ions that are formed when these atoms react.



3: Draw electron cross and dot structure for the following molecules:

- COCl_2 , a poisonous gas called phosgene that has been used in World War-II.
- HOCl , hypochlorous acid is unstable, decomposes to liberate atomic oxygen that makes HOCl a strong oxidizing agent.

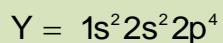
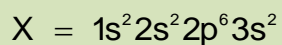
4: The table below shows the properties of four substances:

Substance	Melting point	Electrical Conductivity	
		In solid state	In molten state
A	High	NIL	NIL
B	High	NIL	Good
C	Low	NIL	NIL
D	High	Good	Good

- Which substance is a metal?
- Which substance is an ionic compound?
- Which substance is a covalent compound?
- Which substance is a non-metal?



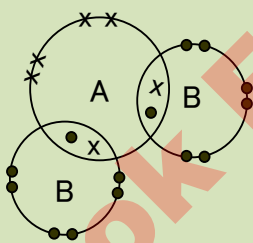
5: Electronic configuration of two elements X and Y are given below:



Predict which of the following compounds is likely to form when X and Y react? Explain.

- (a) A covalent compound of formula XY_2
- (b) An ionic compound of formula XY_2
- (c) An ionic compound of formula XY
- (d) An ionic compound of formula X_2Y

6: The following figure shows the electron dot and cross diagram of molecule AB_2 . Which of the elements could be A and B? Aparise.



7: Illustrate the total number of shared electrons in a molecule of CO_2 ?

Content Authors

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She obtained her Master' degree in Chemistry from Quaid-i-Azam University, Islamabad, and has over twenty eight years of teaching experience. She is serving in Islamabad Model College for Girls, F-10/2 Islamabad.

Along with teaching, she has been contributing lot extensively to the promotion of Chemistry. She has translated Textbook of Chemistry from English to Urdu for class XI, for the National Language Authority. She has also co-authored the Textbook of Chemistry for class XII for Allama Iqbal Open University, Islamabad. Besides this she has been involved in writing, editing, and comparing Television programs of Chemistry for Secondary classes.

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He is an alumnus of CM Boys High School Wah Cant, Gordon College Rawalpindi and Quaid-i-Azam University Islamabad. He obtained his master' degree in Chemistry in 1979 and in 1988 he was awarded the M.Phil degree by the same Alma Mata.

In 1980, he launched himself into the teaching profession, when he joined the Chemistry Department of Army Burn Hall College Abbottabad. In 1982, he joined the Islamabad College for Boys, G-6/3, Islamabad and also served as Principal in various colleges in Islamabad. He retired as Principal from Islamabad College for Boys (ICB) G-6/3, Islamabad. On the occasion of the Silver Jubilee celebrations of I.C.B, G-6/3 he was declared as the best teacher in Chemistry and awarded a gold medal.

His rich experience in teaching Chemistry, has enabled him to serve as member, National Review Committee from 2002-2006 for finalizing textbook manuscripts in the subject of Chemistry for Secondary and Higher Secondary classes, developed by various Textbook Boards. He is also Managing / Co-Author of several textbooks. For queries about book in question, please contact at: prof.iqtedar@gmail.com.



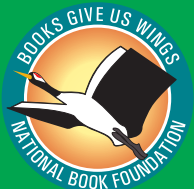
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مركزِ یقین شاد باد!

پاک سرزمین کا نظام قوتِ اخوتِ عوام
قوم، ملک، سلطنت پائندہ تابندہ باد!
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